

DESIGN OPTIMIZATION OF WATERJET
PROPULSION SYSTEMS FOR HYDROFOILS

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(1966)

SUBMITTED IN PARTIAL FULFILLMENT OF THE
REQUIREMENTS FOR THE DEGREE OF
OCEAN ENGINEER AND THE DEGREE OF
MASTER OF SCIENCE IN
MECHANICAL ENGINEERING

at the

MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May, 1972

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Submitted to the Department of Ocean Engineering on May 12, 1972, in partial fulfillment of the requirements for the degree of Ocean Engineer, and to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of Master of Science in Mechanical Engineering.

ABSTRACT

A generalized waterjet propulsion system in a sub-cavitating hydrofoil craft is considered for design and performance estimation. Independent system parameters of jet velocity ratio, inlet velocity ratio, and nacelle inlet diameter to maximum diameter ratio are varied to search for the optimum system. The optimum system is defined as the minimum total propulsion system weight. The optimization scheme utilizes a directed search without the calculation of derivatives, and was chosen for its simplicity, versatility, and rapidity. The ducting system is divided into components for head loss calculations. For a given design, total head losses in the duct are computed by means of experimental data and empirical equations, enabling pump, reduction gear, and prime mover design to be completed. Results for a sample craft are included which indicate that hydrofoils should be designed about the gas turbine, due to the discrete power levels that are available. Suboptimizing the nacelle design may lead to an overall less optimum system design. A general lack of information was noted on nacelle, cascade corner, and three dimensional diffuser design and performance prediction. A FORTRAN computer listing and flow charts are included.

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ACKNOWLEDGEMENT

This effort would be lacking if I did not acknowledge those who assisted me towards its completion.

Professor A. Douglas Carmichael was not only generous with his time and advice, but invariably asked the question that pointed to the heart of the problem. I am grateful for being shown the way when I have strayed from the path, and for the many hours this guidance has saved me.

Bryan T. Conner and Robert C. Percival were more than simply co-workers, solving their own segments of the overall design problem. They were helpful with their time and energy on problems, not their own, and were readily available to render assistance if the need arose.

Finally, but by no means the least, my thanks to my wife, Cathy, for her unflagging aid and support in both academic and family matters.

TABLE OF CONTENTS

	Page
Title Page.....	1
Abstract.....	2
Acknowledgement.....	3
Table of Contents.....	4
List of Figures.....	5
List of Symbols in Text.....	7
Chapter 1 - Introduction.....	10
Chapter 2 - Design Methodology.....	12
Chapter 3 - Discussion of Results.....	23
Chapter 4 - Conclusions and Recommendations.....	31
Bibliography.....	33
Figures.....	39
Appendices	
A. Optimization.....	45
B. Nacelle.....	51
C. Elbow.....	52
D. Strut.....	56
E. Pump Inlet Piping.....	57
F. Pump.....	60
G. Nozzle.....	62
Figures.....	64
List of Symbols in Program.....	73
Flow Diagrams.....	109
Program Listing.....	155

LIST OF FIGURES

Number	Title	Page
1	General Ducting Configuration	14
2	Typical Hydrofoil Lift to Drag vs Speed Curve	17
3	Design Methodology Flow Diagram	20
4	Weight Ratio vs Range	39
5	Weight Ratio vs Displacement	40
6	Sample Output Data	41
7	Weight Ratio/Propulsive Coefficient vs Displacement	44
8	Generalized Pattern Search Flow Diagram	54
9	Elbow	65
10	Minimum Elbow Loss Coefficient	66
11	Elbow with One Splitter	67
12	Elbow Loss Coefficient with Thin, Circular-Arc Turning Vanes	68
13	Expansion Factor for Straight Walled, Two-Dimensional Diffuser	68
14	Junction and Diverging Ducts	69
15	Junction Loss Factor, λ	70
16	Generalized Optimization Executive Program Flow Diagram	71
17	Generalized Weight Estimation Executive Program Flow Diagram	72
18	Test Program Flow Diagram	109
19	Subroutine H2OJT Flow Diagram	110
20	Subroutine FCT Flow Diagram	114
21	Subroutine NACEL Flow Diagram	118

Number	Title	Page
22	Subroutine ELBOW Flow Diagram	123
23	Subroutine STRUT Flow Diagram	126
24	Subroutine JUNCT Flow Diagram	128
25	Subroutine PIPE Flow Diagram	129
26	Subroutine DIVRG Flow Diagram	130
27	Subroutine NOZZL Flow Diagram	132
28	Subroutine PUMP Flow Diagram	134
29	Subroutine GEAR Flow Diagram	140
30	Subroutine FUEL Flow Diagram	142
31	Subroutine CFS Flow Diagram	143
32	Subroutine TABLE Flow Diagram	144
33	Subroutine PTPRN Flow Diagram	147
34	Subroutine OUTPUT Flow Diagram	149

List of Symbols

A	- Cross sectional area of duct, square foot
c	- Strut chord, foot
C	- Loss coefficient factor for diffuser, based on equivalent angle
C_1, C_2	- Constants
C_d	- Nacelle drag coefficient, based on wetted surface area
C_{ds}	- Strut drag coefficient, based on planform area
C_{dsp}	- Spray drag coefficient, based on planform area
C_{fs}	- Schoenherr friction coefficient
D	- Drag, pound force
D_e	- Mean hydraulic diameter, foot
D_i	- Inlet diameter, foot
D_j	- Jet diameter, foot
D_m	- Nacelle maximum external diameter, foot
D_t	- Nozzle throat diameter, foot
f	- Moody friction factor
g	- Acceleration of gravity, foot per second squared
h_a	- Atmospheric pressure head, foot
h_{elev}	- Elevation head, foot
h_i	- Total head loss to pump inlet, foot
h_n	- Nozzle head loss, foot
h_t	- Total duct head loss, foot, $h_t = h_i + h_n$
h_v	- Vapor pressure head, foot

K_e	- Expansion loss coefficient of diffuser
K_t	- Total loss coefficient
K_1, K_2	- Loss coefficients at different Reynold's numbers
L	- Lift, pound mass
L_j	- Nozzle length, foot
L_n	- Nacelle length, foot
\ln	- Natural logarithm
NPSH	- Net positive suction head, foot
p	- Static pressure, pound force per square foot
P	- Wetted perimeter, foot
Q	- Volume flow rate, cubic foot per second
r_i	- Inside bend radius, foot
r_{ia}	- Inside subdivided elbow radius, foot
r_o	- Outside bend radius, foot
r_{oa}	- Outside subdivided elbow radius, foot
R	- Radius of bend centerline, foot
Re	- Reynolds number
RO	- Internal duct radius, foot
RPM	- Revolution per minute
SFC	- Specific fuel consumption, pound fuel per horsepower hour
SHP	- Shaft horsepower
t	- Strut thickness, foot
T	- Thrust, pound force
T_v	- Thrust vertical component, pound force

V	- Average water velocity, foot per second
V_i	- Inlet velocity, foot per second
V_j	- Jet velocity, foot per second
V_o	- Craft velocity, foot per second
W	- Weight, pound mass
z	- Elevation above reference level
α	- Numerical factor in bend loss coefficient
β	- Optimum nozzle depression angle, degree
θ	- Bend angle, measured from horizontal, degree
2θ	- Equivalent angle of diffuser, degree
λ	- Factor in mixing loss coefficient of junction
ρ	- Water density, pound force second squared per foot to the fourth
σ	- Thoma's cavitation index
ϕ	- Angle of junction, degree
χ	- Loss coefficient correction for Reynold's number
ψ	- Nozzle angle, degree

CHAPTER 1 - INTRODUCTION

The use of waterjets for the propulsion of marine vehicles at conventional ship speeds has not been considered comparable to that of propellers. Although the concept is quite old, the disadvantages of waterjets have not been overcome and the advantages not realized. At the speeds considered, the low system efficiency, large system weight and relatively sophisticated technology required were sufficient to virtually exclude waterjets from competition with propellers. With the advent of high speed craft however, this means of propulsion is receiving a renewed interest as a practicable system. Among the possible advantages that may be realized are (refs. 1,2):

- a. Reduced noise and vibration
- b. Fewer system components
- c. Elimination of underwater appendages
- d. Elimination of complex transmission machinery
- e. Limited draft applications
- f. Simplification of steering devices

For hydrofoil craft, the waterjet looks particularly attractive. It neatly avoids the problem of conventional propellers in power transmission (refs. 3,4). For this reason, waterjet propulsion development to-date has been primarily concerned with hydrofoil applications. In addition, new concepts in ships, such as surface effect

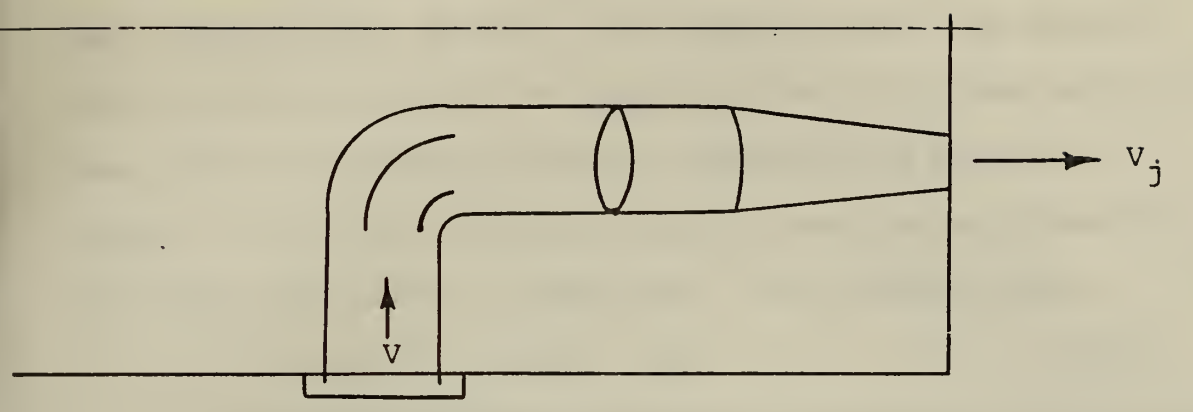
ships and captured air bubble craft, are now including consideration of waterjets as a possible propulsion system. With this surge of interest, the need to go beyond the practical "Will it work?" engineering design method has become paramount. The question has become, "What is the best waterjet propulsion system for the craft under consideration?". Answering this question requires a strictly formulated methodology previously not required in make-it-work technological levels. No longer is it satisfactory to find some point, any point, above the minimum acceptable level. The scope has been enlarged to pinpointing the optimum within the entire domain of feasibility. The immensity of this task coupled with its relative lack of need has hampered the implementation of a methodology. Hydrofoils have demonstrated the need, while computers provide the invaluable aid for the required computations; therefore, an optimization methodology has been developed.

CHAPTER 2 - DESIGN METHODOLOGY

To initialize the design method, a clear definition of the desired objective must be given. In the present instance, the definition is the answer to the question, "What is meant by an optimal waterjet propulsion system?". The choice of an optimum must adequately describe the system without bias. It is readily apparent that whatever optimum is chosen, it will have a strong effect on the methodology employed. The current most commonly used descriptor is the propulsive efficiency which is defined as the ratio of the power required to the power output of the plant (ref. 5). Efficiencies suffer from differences in definition and thus vary in their relative importance to system optimization. Minimum power required to propel the craft at the desired speeds is sometimes utilized as an optimization objective with the advantage of being readily calculable and understood. A disadvantage is that a gas turbine, which is a commonly used prime mover on account of its low weight to power ratio, operates most efficiently at its maximum power level. Hence, there exists a natural trade-off between the most efficient propulsion and the margin required for growth in the ensuing years of the craft's life. Minimum power calculations are certainly necessary but provide a somewhat questionable optimum. In an attempt to avoid vagaries of definition and usage and

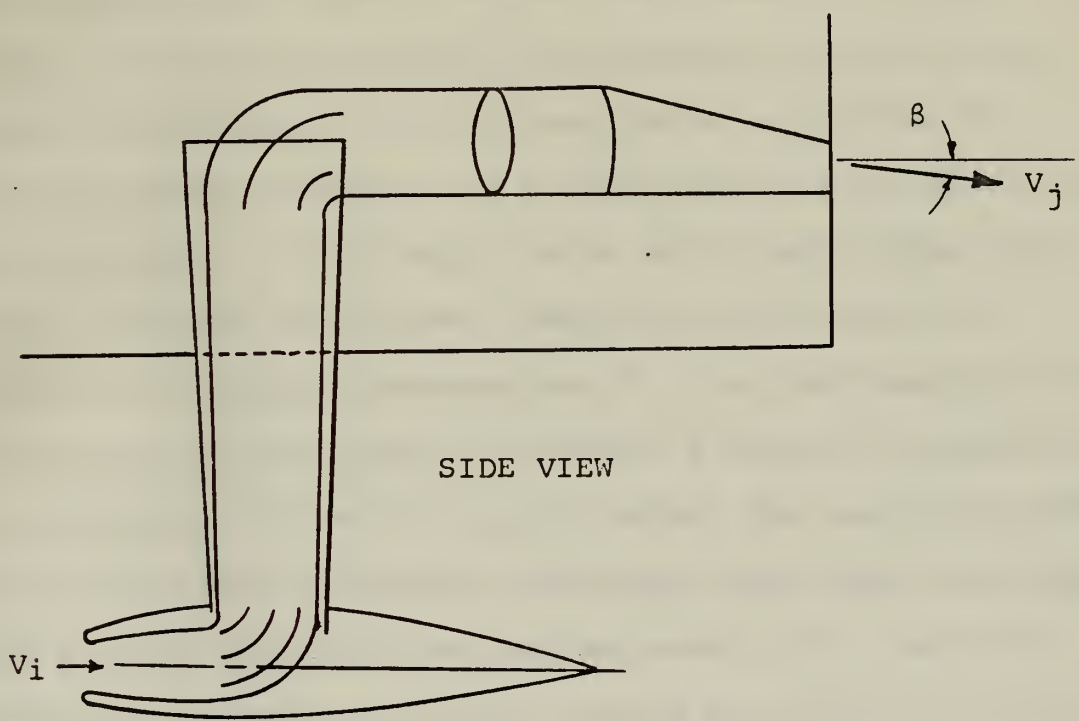
to remove doubts of sufficiency, the goal of optimization or the system "cost" may be defined differently. The "cost" of any system should reflect the disadvantages of that system without weighting one disadvantage over another. Two disadvantages of waterjet propulsion systems mentioned previously are a large system weight, in part due to the entrained water, and a low overall system efficiency. Inefficiencies are, however, necessarily manifested in increased weight, be it added required fuel, another pump stage, or larger ducting. Recall, too, that hydrofoils are weight limited vehicles. A unique number that reflects these realizations is a suitable definition of the weights attributable to the propulsion system (ref. 5). The propulsion system weight shall be defined as the sum of all weights of the structural components, prime movers, fuel, pumps, gearbox, ducting, and entrained water above the mean waterline. If, for a given craft, the displacement is considered constant, then minimization of the propulsion system weight is equivalent to maximizing the craft payload. Thus, a propulsion system shall be defined as optimal if, in addition to fulfilling the propulsion requirements, it adds the minimum weight of any propulsion system to the vehicle.

The generalized waterjet propulsion system for hydrofoils utilized in this study is depicted in Figure 1. It should be noted that this configuration permits



TOP VIEW

$V_o \leftarrow$



SIDE VIEW

FIGURE 1 GENERAL DUCTING CONFIGURATION

considerable variation by the changing of a few lengths and angles of the ducting. The water enters the nacelle under ram pressure and is ducted up the strut and into the pump where the energy input is converted to kinetic energy in the jet. Thus the thrust reaction is generated, providing the craft's propulsion. In equation form,

$$T = \rho Q (V_j \cos(\beta) - V_o) \quad (1)$$

In any optimization procedure, the formulation of the method requires the knowledge of the parameters to be varied. The number and selection of these parameters contributes significantly to the applicability of the method. The parameters must be necessary and sufficient system descriptors, and it is desirable to utilize the minimum number required. If M operations are performed in the evaluation of one design point and N independent parameters describe the system, then the total number of operations required increases as M^N . The sufficiency of the description of the system is clearly a choice of adequacy. The variables that most strongly affect the resulting system should be chosen as system parameters while other variables that produce only minor variations over a wide range of values on the essential design should be defined, or even somewhat arbitrarily chosen, to suit the needs of the design.

Examination of equation (1) reveals that for a given craft and associated mission, only the flow rate and jet velocity are unknown. The one-dimensional continuity

equation for an incompressible fluid

$$A_1V_1 = A_2V_2 = Q \quad (2)$$

indicates that choice of jet velocity will determine the jet area. The first non-dimensionalized system parameter, then, shall be V_j/V_o , defined at the cruise point. Knowing the flow rate from the jet, the same reasoning may be applied to the inlet which results in the second system parameter of V_i/V_o , where V_i is defined in the cruise condition at the point of minimum area in the nacelle. The third and last system parameter, for reasons that will be explained in Chapter 3, shall be D_i/D_m , where D_i is the diameter of the inlet at the point of V_i .

Finally, the minimum amount of information needed to specify the craft and its mission must be determined. A typical drag to craft speed curve is shown in Figure 2. The "hump" at the lower speeds represents the take-off point, i.e., when the hull lifts free of the water and the craft is foilborne, and generally occurs at speeds that are approximately 50% of the cruise speed. The sizing of the propulsion system then is dependent on both the cruise and take-off conditions. The minimum information required is the following:

- a. Displacement
- b. Range
- c. Prime mover
- d. Craft Speed, at take-off and cruise

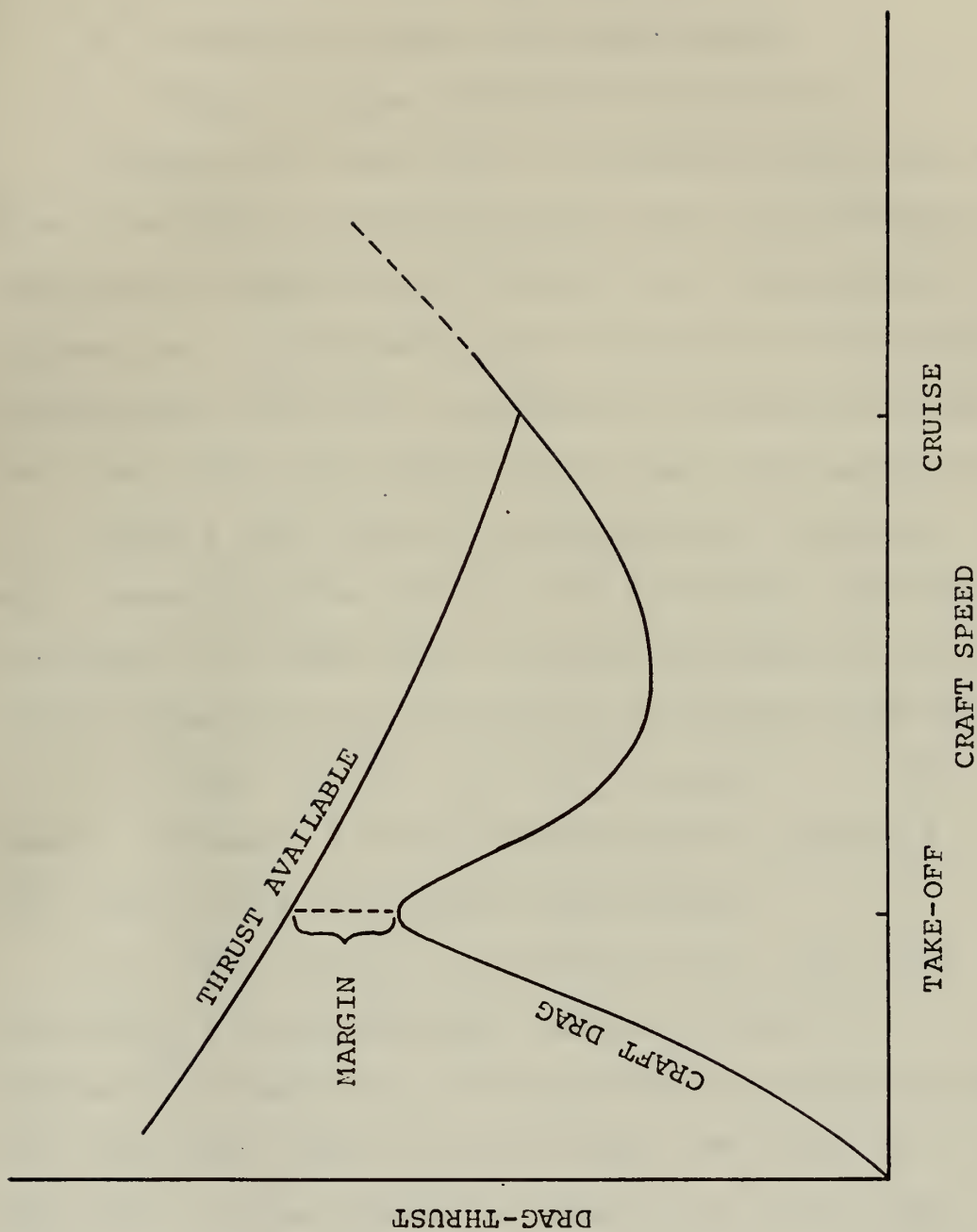


FIGURE 2 TYPICAL HYDROFOIL LIFT TO DRAG VS. SPEED CURVE

- e. Craft Drag, at take-off and cruise
- f. Depth of submergence of foil
- g. Distance of strut from transom
- h. Distance of pump exit from transom
- i. Height of pump centerline above keel

Although the prime mover is assumed to be a gas turbine, knowledge of the particular type of gas turbine is important in consideration of both fuel and power requirements. It is readily seen that the last four input requirements define the approximate configuration while the first five items describe the craft size and mission.

Knowing the required ingredients and the desired result leaves only the recipe to be set forth. For the traverse of an ideal fluid between two points in a closed conduit, Bernoulli's equation may be applied such that

$$p_1 + \frac{1}{2}\rho V_1^2 + \rho g z_1 = p_2 + \frac{1}{2}\rho V_2^2 + \rho g z_2 \quad (3)$$

where 2 indicates a station downstream of station 1.

For a real fluid with losses this becomes

$$p_1 + \frac{1}{2}\rho V_1^2 + \rho g z_1 = p_2 + \frac{1}{2}\rho V_2^2 + \rho g z_2 - \Delta p_{12} \quad (4)$$

where Δp_{12} = losses between stations 1 and 2.

Although this equation can be applied only along a streamline and hence cannot be used across the pump, it is applicable to the ducting on either side of the pump. The continuity equation provides the information that the ducting velocities are determined by geometric configuration. Starting from a known point, e.g. the water surface,

and following the water through the duct leaves only the losses as unknown. Estimation of the losses may be accomplished based on duct size and shape (ref. 8). This yields the needed information for the pump design.

Following the flow diagram of Figure 3, and recalling the previous discussion, the choice of the system parameters by the technique described in Appendix A determines the inlet and outlet geometry. Knowledge of the jet area determines the flow rates at both cruise and take-off. Water is ingested into the nacelle at velocity V_i . The parameter D_i/D_m sets the amount of diffusion possible prior to entry into the strut elbow. Determination of the nacelle length provides both a drag estimate and the head loss in the nacelle duct as described in Appendix B. The strut elbow will exhibit large losses due to the low aspect ratio (width/depth) of the duct as it conforms to the shape required for the strut and due to the relatively large velocities. The use of guide vanes will minimize the losses by increasing the aspect ratio. Assuming the inlet and outlet areas are the same, the losses in the elbow may be calculated by the method described in Appendix C. The strut diffuser area ratio is set to avoid cavitation in the downstream ducting and to reduce the inflow velocity to the pump. Sizing the internal flow area permits an estimate of the exterior dimensions which are sized up to cavitation limits. For more information,

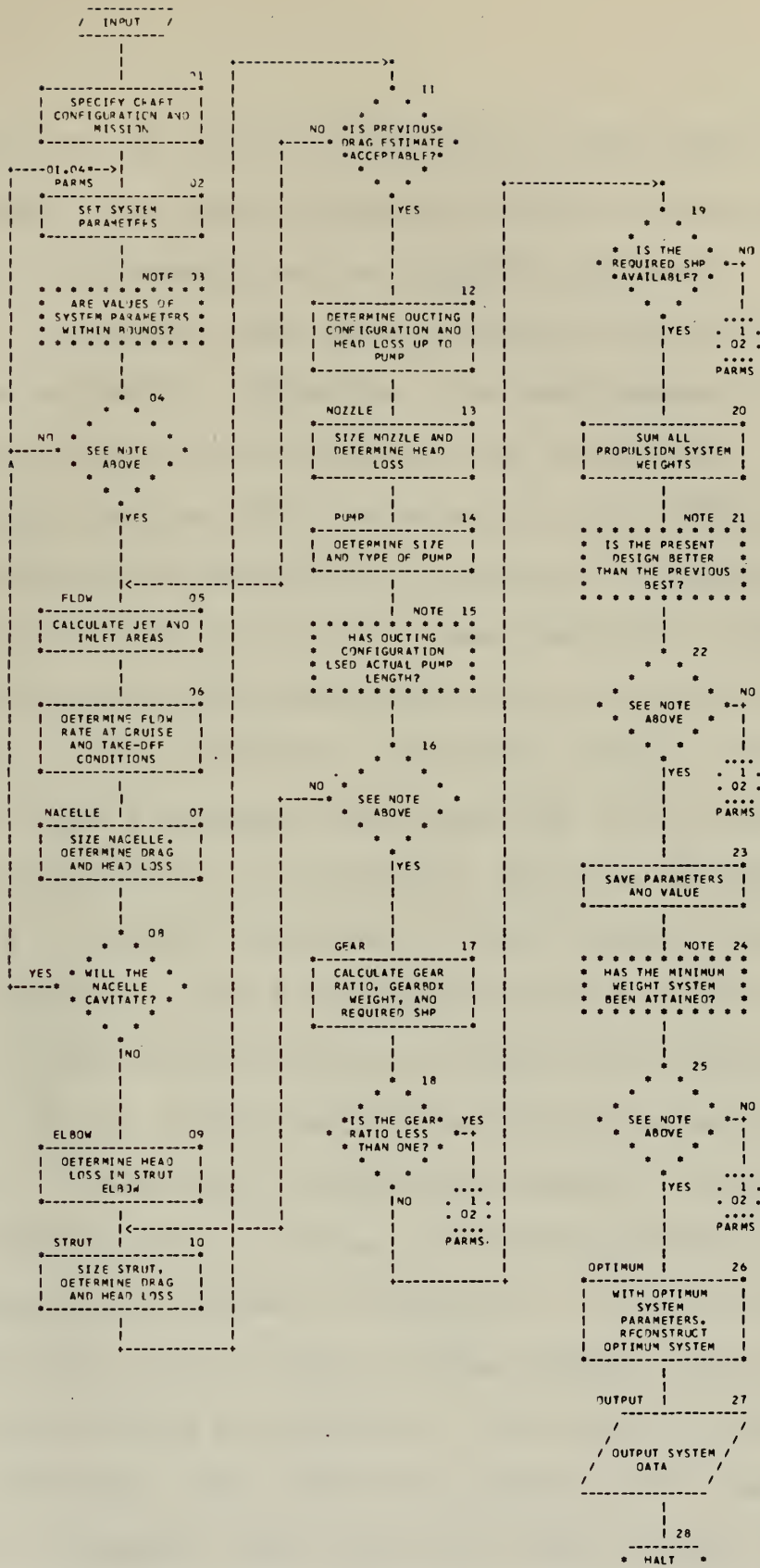


FIGURE 3 DESIGN METHODOLOGY FLOW DIAGRAM

see Appendix D. The drags attributable to the strut and spray are estimated. The newly calculated nacelle, strut, and spray drags are compared to the original estimates. If the deviation is excessive, the drag estimate is revised and the problem restarted. Otherwise, the head losses in the strut due to friction and diffusion are calculated. Entry into the hull from the strut is made via a 90° elbow for which the losses are calculated as before. It should be noted that this elbow will have a more favorable aspect ratio as a result of the strut shape and will require fewer guide vanes. Coupled with the decreased velocity, the losses will show a decrease from those due to the strut elbow. Determination of the ducting required, as described in Appendix E, permits estimation of the ducting losses therein. Summation of all the losses prior to the pump and knowledge of the inflow velocity provide the cavitation information in the form of net positive suction head (NPSH) to the pump. Adding the nozzle losses permits calculation of the pump head required. The method for determining the nozzle losses may be found in Appendix G. This is sufficient to determine the size and type of pump needed, the details of which may be found in Appendix F. The specifications of the prime mover are then utilized to specify the gearbox parameters of gearbox ratio and power which in turn indicates the SFC required in the cruise condition. Since the

amount of fuel required for the endurance specified is calculable, the entire propulsion system is fully defined in dimensions, configuration, weights, and particular components. Summing all the component weights yields the desired system weight. This concludes the evaluation of a propulsion system weight for the chosen system parameters. The optimization routine utilizes the weight information, selects a new set of system parameter values and the cycle begins anew. Ultimately, the minimum weight system is located and the process completer.

CHAPTER 3 - DISCUSSION OF RESULTS

A sample output is depicted in Figure 6. The first page is predominantly a repetition of the input data and is printed out upon call to the program. The second and third pages are the resulting optimized system data that is printed for each configuration of pumps and gas turbines considered. Hence the designer can see at a glance the pertinent information required for a preliminary design as well as compare the alternative configurations that might be feasible and competitive designs.

There are a number of features within the results that are not immediately obvious. First and foremost is the problem of results exceeding a system limitation. For example, having required cruise shaft horsepower exceeding the maximum normal horsepower of the engine. Within the program during the optimization, such designs are, of course, rejected. For the print out, it was considered that knowledge of the resulting "optimum" was desirable, however erroneous it may be. One of the forcing influences on this decision was the variability of the total drag estimation and thus the flow rate. If the optimum system resulted in a value that was at a boundary, a slight change in, say, flow rate might cause the value to exceed the boundary and hence result in a rejected design. In other words the optimum system is not identically reproducible. The significance of this fact will be amplified in the

conclusions section. This lack of reproducibility results primarily from the iterations for drag estimation. Each new estimation is compared to the previous estimation and accepted if within 5% of the former value. Otherwise the flow rate is adjusted for the new drag and the nacelle and strut are redesigned. In the case of the 400 ton craft used, 5% of the total drag is on the order of 4000 pounds force in the cruise condition. Thus, starting from the same system parameter values but with different initial drag estimates may result in a total drag differing by 5% in the output with corresponding differences in the system.

Secondly, the resulting design is obviously constrained by the ducting configuration used. Hence direct comparison with existing craft is not valid until the configuration is modified to conform to that of the craft.

At the inception of this project, it was believed that the duct area ratio of the strut was a system parameter to be varied independently. Clearly a lower bound on this parameter is that amount of diffusion required to avoid cavitation in the hull ducting. It was felt, however, that the pump, gear and fuel weight calculations might reflect a lower overall weight if the pump inflow rate was reduced. The results did not justify this assumption. The system unerringly chose the strut with the minimum required diffusion, which meant minimum weight. The principal reason for this result is that the pump design is in terms

of total head. Hence the pump effectively never "sees" the amount of static head presented to it. The pump is affected only by the differences in ducting losses which are reflected in both the NPSH and pump head. Thus the net effect is of secondary importance and is not significant enough to change the area ratio of the strut. For this reason the area ratio of the strut ducting was rejected as a system parameter and is presently determined as required by cavitation limitations or pump inlet area.

The initial nacelle design method chose the largest inlet to maximum diameter ratio permissible by exterior cavitation. This ratio was tempered by the amount of diffusion required to avoid cavitation in the strut elbow. Assuming the same inlet velocity ratio, would more diffusion than the minimum required permit an overall lesser weight system? In other words, does the optimum system require the optimum nacelle or might an off design nacelle be used resulting in a lesser weight system? The use of the nacelle diameter ratio, DIDM, as a system parameter provides the opportunity to investigate this question. The current results are somewhat inconclusive due to the influence of other factors. Tentatively, it is suggested that for some designs, the use of DIDM as a system parameter is justified and results in a better system design. It is recommended that investigation of this question be pursued for determination of what constitutes the basis of nacelle

design in regards to system performance.

Perhaps the most significant conclusion is that the choice of engine is extremely important in the resulting optimum system. The first reason for this is that the gas turbine is presently available only at discrete power levels. Since fuel weight is large relative to the other system weights, the operation of a gas turbine at a point significantly off its design point will result in a large increase in fuel weight and thus system weight. The net effect is that, given the opportunity to avoid the penalty in fuel weight, the system tends towards the maximum SHP permitted by the engine, and will drive the jet velocity ratio as high as possible to achieve this SHP. This also results in a low flow rate, low drag and low propulsive coefficient. If the engine is slightly large for the craft, then the results will show a high jet velocity ratio, SHP per engine at the maximum permissible level, which may be limited by take-off or cruise SHP, and a low propulsive coefficient. If the engine is so large that there is no power limitation, the jet velocity ratio will be very high and the SHP per engine relatively low resulting in a very low propulsive coefficient due to large total SHP and a high system weight. The effect of an engine that is barely adequate is a lowered jet velocity ratio in an effort to reduce the SHP requirements. The trade-off here is the large flow rate required to compensate for the low jet

velocity ratio and the large drag that results from attempting to accomodate the flow rate in the nacelle and strut. Thus SHP is being forced up and the system may never achieve an acceptable horsepower level.

This power level sensitivity is so strong that it is abundantly clear that hydrofoils should be designed around a particular gas turbine. Choice of a desired displacement and the use of an adequate prime mover may result in a poor design and inefficient use of the gas turbine. Choice of the gas turbine and permitting the displacement to be chosen at the point of best engine operation will result in a more efficient and more effective design. Thus it is recommended that another version of this program be created that chooses the best displacement given the engine. It is also suggested that perhaps the concept of hydrofoil craft design be revised to accomodate the fact that the engine choice determines the best design. Figure 7 shows the minimum weight ratio for one LM2500 and one pump with a lift to drag ratio of 11.3. The results show the optimum weight ratios with and without fuel do not coincide. The propulsive coefficient is drawn to show the trade-off between maximizing SHP and maximizing the propulsive coefficient.

The choice of an engine also affects the reproducibility of the optimum system design. If the engine is smaller than desirable, VJVO is driven as high as the SHP permits.

When the optimum system parameters have been found and the optimum system is to be regenerated, the design process is reinstituted. During this final design, iterations in craft drag are again required to determine the final flow rate and size of the system. Thus the net result may be a system slightly different from the one originally found with least weight. And in the case of a system already on a boundary, the resulting system may exceed the limits placed on the optimization process. It is to be expected that the deviation will be small but nonetheless present. The results in such a case should be interpreted as optimal at the boundary and not an unsatisfactory design. If the deviation is significant and the other system values reflect it, the interpretation should be that the system was unable to be optimized within the limits. The most common example of this occurs when the cruise or take-off SHP of the engine is insufficient to meet the craft requirements.

The effect of range on the system design is shown in Figure 4. The LM 2500 is a power limited engine for the four hundred ton craft at forty-two knots. The FT4C-2, however, is so large that maximum power is never attained in this craft. The effect of lower SFC and operation at maximum power favors the LM 2500 at the longer ranges. As it should be, the weight ratio without fuel is essentially constant for both engines, although the weight ratio for the

LM 2500 is higher, presumably on account of the power limitation. Similarly, the jet velocity ratio remains constant as does the flow rate, but the inlet velocity ratio tends to increase with increasing range. The nacelle diameter ratio, on the other hand, shows no consistent pattern. The effect of variation of displacement by 10% is shown in Figure 5 for the FT4C-2 for one and two pumps.

The results show a surprising sensitivity to the starting values of the system parameters. When arbitrarily deviated by twenty per cent from the present values, the results were unpredictable. The current values, however, have shown good stability with test craft ranging from fifty to seven hundred fifty tons and from forty to fifty knots. The reason for this apparent instability is unknown. The step sizes appear to be acceptable at any size above a threshold value. Some conditions will not permit location of the optimum if the step size is too small. The current step sizes, although generally too large, have performed well for the test craft above. The probable rationale is that the large step size permits a search over a wider, more extreme range of system values, but in the event that the step is too large, the step size will rapidly be reduced to an acceptable level.

The lack of experimental data and analytical techniques has been noted in several areas. The nacelle design is a case in point. Although nacelles have been studied exten-

sively by the aeronautics industry, the application of nacelles to a water environment has been neglected and consequently, design considerations have not been defined. The design of cascaded corners has somewhat more experimental data for loss estimation, but the scatter of the data and the lack of definitive design information render elbow design a vague approximation at best. Three dimensional diffusers are likewise an unexplored domain. The effect of changes of ducting shape on losses is not treated in the literature for straight pipe. Loss estimation for changing shape in elbows is treated, but only for rectangular forms. It is apparent that the program results contain a great deal of information, but it is also evident that the interpretation of the results can be improved by a more thorough study of runs for different craft, configurations, and missions. A study of the effects and interactions of such changes will provide a finer understanding of the import of the results.

CHAPTER 4 - CONCLUSIONS AND RECOMMENDATIONS

A method of optimizing a waterjet propulsion system for hydrofoils has been developed and tested with a four hundred ton hydrofoil at a cruise speed of forty two knots. Other craft have verified the importance of the selection of the gas turbine for a particular craft. It is recommended that a version of this program be adapted to determine the optimum displacement for a given engine.

Although originally considered important, the amount of diffusion in the strut should be the minimum required to avoid cavitation in the ducting or the minimum required by the pump, whichever is greater. The design of the nacelle need not be at the limits of cavitation, but should be integrated into the total system design to provide a lesser weight propulsion system. It is recommended that a study of nacelle design be initiated to determine the interaction of the nacelle and the propulsion system.

The initial values of the system parameters may affect the operation of the optimization procedure. A determination of the cause of this lack of stability should be made. The magnitude of the step sizes of the parameters has little effect on the program provided they are sufficiently large.

A general lack of data and design information is prevalent for fluid flow in closed conduits. This is especially noted for ram inlet design, cascaded corners, three dimensional diffusers, and changes of pipe shape.

The program provides a unique facility for the preliminary designer to rapidly ascertain the optimum waterjet propulsion system design and performance. Many results should be studied to deduce the complete real world interpretation of a computer generated design.

BIBLIOGRAPHY

1. Brandau, J.H., Performance of Waterjet Propulsion Systems - A Review of the State of the Art, Journal of Hydronautics, Vol.2,no.2, pp.61-73, April 1968
2. Manins, P.C., A Study of Hydraulic Jet Propulsion in a Destroyer, Australian Aeronautical Research Lab., ARL/ME 316, July 1970
3. Johnson, V.E., Waterjet Propulsion for High Speed Hydrofoil Craft, AIAA Paper 64-306, June 1964
4. Levy, J., The Design of Waterjet Propulsion Systems for Hydrofoil Craft, Journal of Marine Technology, Vol. 2, no.1, pp. 15-26, January 1965
5. Hatte, R. and Davis, H., Selection of Hydrofoil Waterjet Propulsion Systems, AIAA Paper 66-732, August 1966
6. Traksel, J. and Beck, W.E., Waterjet Propulsion for Marine Vehicles, AIAA Paper 65-245, March 1965
7. Arcand, L. and Comolli, C., Optimization of Waterjet Propulsion for High Speed Ships, Journal of Hydronautics, Vol.2, no.1, pp.2-8, 1968
8. Kim, H.C., Hydrodynamic Aspects of Internal Pump-jet Propulsion, Journal of Marine Technology, pp.80-98, January 1966
9. Conner, B.T., A Study of Ram Type Intake Parameters, Ocean Engineer Thesis, MIT, June 1972
10. Hoerner, S.F., Fluid Dynamic Drag, published by author, 1965
11. Ito, H., Pressure Losses in Smooth Pipe Bends, Trans. ASME, Series D, pp.131-143, March 1960
12. SAE Aerospace Applied Thermodynamics Manual, Society of Automobile Engineers, New York, 1969
13. Engineering Sciences Data Report 00.02.07, The Pressure Loss for Incompressible Turbulent Flow in Smooth Circular-Arc Bends, Royal Aeronautical Society/Inst. Mech. Engr., London, 1963
14. Sherman, P.M. and Lincoln, F.W., Ram Inlet Systems for Waterjet Propulsions, AIAA Paper 69-418, May 1969

15. Techo, R. et al, An Accurate Equation for the Computation of the Friction Factor for Smooth Pipes from the Reynolds Number, Journal of Applied Mechanics, Vol. 32, no. 2, p. 443, 1965
16. Vazsonyi, A., Pressure Loss in Elbows and Duct Branches, Trans. ASME, Vol. 66, pp. 177-183, 1944
17. Percival, R.C., Optimization of Waterjet Propulsion Pumps for Hydrofoil Applications, Ocean Engineer Thesis, MIT, June 1972
18. Karnopp, D.C., Search Theory Applied to Parameter Scan Optimization Problems, Ph.D. Thesis, MIT, 1961
19. Nowacki, H., Ed., Computer-Aided Ship Design, Lecture Notes, University of Michigan, June 1970
20. Leopold, R., Mathematical Optimization Methods Applied to Ship Design, DNAME Report 65-8, MIT, October 1965
21. Somekh, D.S., Optimum Oil Tanker Design by a Convergent Random Search Technique, DNAME Report 66-2, MIT, 1966
22. Chrysosostimidis, C., Optimization Methods Applied to Containership Design, S.M. Thesis, MIT, 1967
23. Hooke, R. and Jeeves, T.A., Direct Search Solution of Numerical and Statistical Problems, JACM, Vol. 8, no. 2, pp. 212-229, April 1961
24. Brown, J. and Traksel, J., Waterjet Propulsion Study, Lockheed-California Co., Report LR-178885, Parts 1-5, 1963
25. Contractor, D.N. and Johnson, V.E., Waterjet Propulsion, AIAA Paper 67-361, May 1967
26. Delao, M.M., Practical Considerations of Waterjet Propulsion, SAE Report No. 650630, 1965
27. Dimmock, N.A., The Development of a Simply Constructed Cascade Corner for Circular Cross-Section Ducts, N.G.T.E. Memo. M.78, 1950
28. Dimmock, N.A., Cascade Corners for Ducts of Circular Cross-Section, Brit. Chem. Engg., pp. 302-307, June 1957

29. Doyle, J.P., Study of Propulsion Transmission System for 500 Ton 60 Knot Hydrofoil, Report M-62-19, Gibbs and Cox, November 1962
30. Doyle, J.P. and Hynes, Procedure for Preliminary Design of Waterjet Propulsion System for Hydrofoil Ship, G&C M-66-2, Gibbs and Cox, March 1966
31. Engineering Sciences Data Report 66027, Friction Losses for Fully Developed Flow in Straight Pipes, Royal Aeronautical Society/Inst. Mech. Engr., London, 1966
32. Garcia, A.F., Waterjet Pump Performance Determinations, Naval Engineers Journal, pp. 35-44, October 1970
33. Henry, J.R., Design of Power Plant Installations Pressure-Loss Characteristics of Duct Components, NACA WR-L-208, 1944
34. Hobbs, J.L., Pressure Loss Computations in Incompressible Fluid Flow, General Electric Report APEX-754, July 1961
35. Kline, S.J. et al, Optimum Design of Straight Walled Diffusers, Journal of Basic Engineering, pp.321-331, September 1959
36. Kröber, G., Guide Vanes for Deflecting Fluid Currents with Small Loss of Energy, NACA TM 722, 1932
37. Levy, J. et al, Feasibility Study of Waterjet Propulsion Systems for a 500 Ton Hydrofoil Ship, Aerojet-General Corp., R AGC 2267, April 1962
38. Madison, R.M., Ed., Fan Engineering, Buffalo Forge Company, Buffalo, New York, 1948
39. Moody, L.F., Friction Factors for Pipe Flow, Trans. ASME, Vol. 66, pp. 671-678, 1944
40. Reneau, L.R. et al, Performance and Design of Straight Two-Dimensional Diffusers, ASME Paper 66-FE-10, April 1966
41. Bowen, G.L., The Net Thrust Relationship for Water Jet-Propelled Craft, Hovering Craft and Hydrofoil, Vol. 5, no. 1, pp. 14-15, January 1971

42. Carlson, J.J. et al, Effects of Wall Shape on Flow Regimes and Performance in Straight, Two-Dimensional Diffusers, ASME Paper 66-FE-13, April 1966
43. Colebrook, C.F., Turbulent Flows in Pipes, Journal of Institution of Civil Engineers, London, Vol. 2, pp. 133-156, 1938
44. Dunne, J., Hydrofoil Propulsion System and Design, Hydrofoil Symposium 2G, SNAME, May 1965
45. Fitzroy, N.D., Ed., Fluid Flow Data Book, General Electric Company, Schenectady, New York, 1970
46. Fox, R.W. and Kline, S.J., Flow Regimes in Curved Subsonic Diffusers, Journal of Basic Engineering, Vol. 84, pp. 303-316, 1962
47. Gasiunas, A. and Lewis, W.P., A Theoretical and Experimental Investigation into Propulsion of Seacraft by Waterjet, Proc. Instn. Mech. Engrs., Vol. 178, Pt. 1, no. 7, 1963
48. Gibson, A.H., On the Flow of Water Through Pipes Having Converging or Diverging Boundaries, Proceedings, Royal Society of London, Series A, Vol. 83, p. 366, 1910
49. Gongwer, C.A., Influence of Duct Losses on Jet Propulsion Devices, Jet Propulsion, Vol. 24, no. 6, November-December 1954
50. Gunn, D.J. and Darling, C.W.W., Fluid Flow and Energy Losses in Non-Circular Conduits, Trans. Institution of Chemical Engineers, Vol. 41, no. 4, pp. 163-173, 1963
51. Ito, H., Friction Factors for Turbulent Flow in Curved Pipes, Journal of Basic Engineering, Vol. 81, pp. 123-134, June 1959
52. Klein, G.J., et al, The Design of Corners in Fluid Channels, Canadian Journal of Research, Vol. 3, pp. 272-285, 1930
53. Leiter, M., Application of a Digital Computer to the Design of Non-Linear Optimum Systems, M.S. Thesis, MIT, 1957

54. Lester, J.T., Optimization in Equipment Design, Brit. Chem. Eng., Vol. 6, pp. 851-855, 1961
55. Madison, R.D. and Parker, J.R., Pressure Loss in Rectangular Elbows, Trans. ASME, Vol. 58, pp. 167-176, 1936
56. Patterson, G.N., Note on the Design of Corners in Duct Systems, Aeronautical Research Council, R&M 1773, October 1936
57. Pigott, R.J.S., Pressure Losses in Tubing, Pipe, and Fittings, ASME Paper 49-PET-22, July, 1950
58. Pinckney, S.Z., Optimized Turning Vane Design for an Intake Elbow of an Axial-Flow Compressor, NASA TN D-3083, 1965
59. Powell, M.J.D., An Efficient Method for Finding the Minimum of a Function of Several Variables Without Derivatives, Computer Journal, Vol. 7, pp. 155-162, 1964
60. Robertson, J.M. and Ross, D., Effect of Entrance Conditions on Diffuser Flow, ASCE Proceedings, Vol. 78, Separate No. 141, July 1952
61. Sagi, C.J. and Johnston, J.P., The Design and Performance of Two-Dimensional, Curved Diffusers, Journal of Basic Engineering, Vol. 89, pp. 715-731, December 1967
62. Salter, C., Experiments on Thin Turning Vanes, Aeronautical Research Council, R&M 2469, October 1946
63. Shah, B.V. et al, Some Algorithms for Minimizing a Function of Several Variables, J. SIAM, Vol. 12, pp. 74-92, 1964
64. Shapiro, A.H. and Smith, D.R., Friction Coefficients in the Inlet Length of Smooth Round Tubes, NACA TN 1785, 1948
65. Streeter, V.L., Fluid Mechanics, McGraw-Hill, Inc., New York, 1966
66. Waitman, B.A. et al, Effects of Inlet Conditions on Performance of Two-Dimensional Diffusers, Journal of Basic Engineering, Vol. 83, p. 349, 1961

67. Wilbur, S.W., An Investigation of Flow in Circular and Annular 90° Bends with a Transition in Cross Section, NACA TN 3995, 1957
68. Winter, K.G., Comparative Tests of Thick and Thin Turning Vanes in the Royal Aircraft Establishment 4x3 Foot Wind Tunnel, Aeronautical Research Council, R&M 2589, August 1947
69. Wirt, L., New Data for the Design of Elbows in Duct Systems, General Electric Review, Vol. 30, no. 6, pp. 286-296, 1927
70. Yao, K.M., Pipe Friction Factor Calculation, Water and Sewage Works, Vol. 110, no. 3, March 1963
71. Zangwill, W.I., Minimizing a Function Without Calculating Derivatives, Computer Journal, Vol. 10, pp. 293-296, November 1967

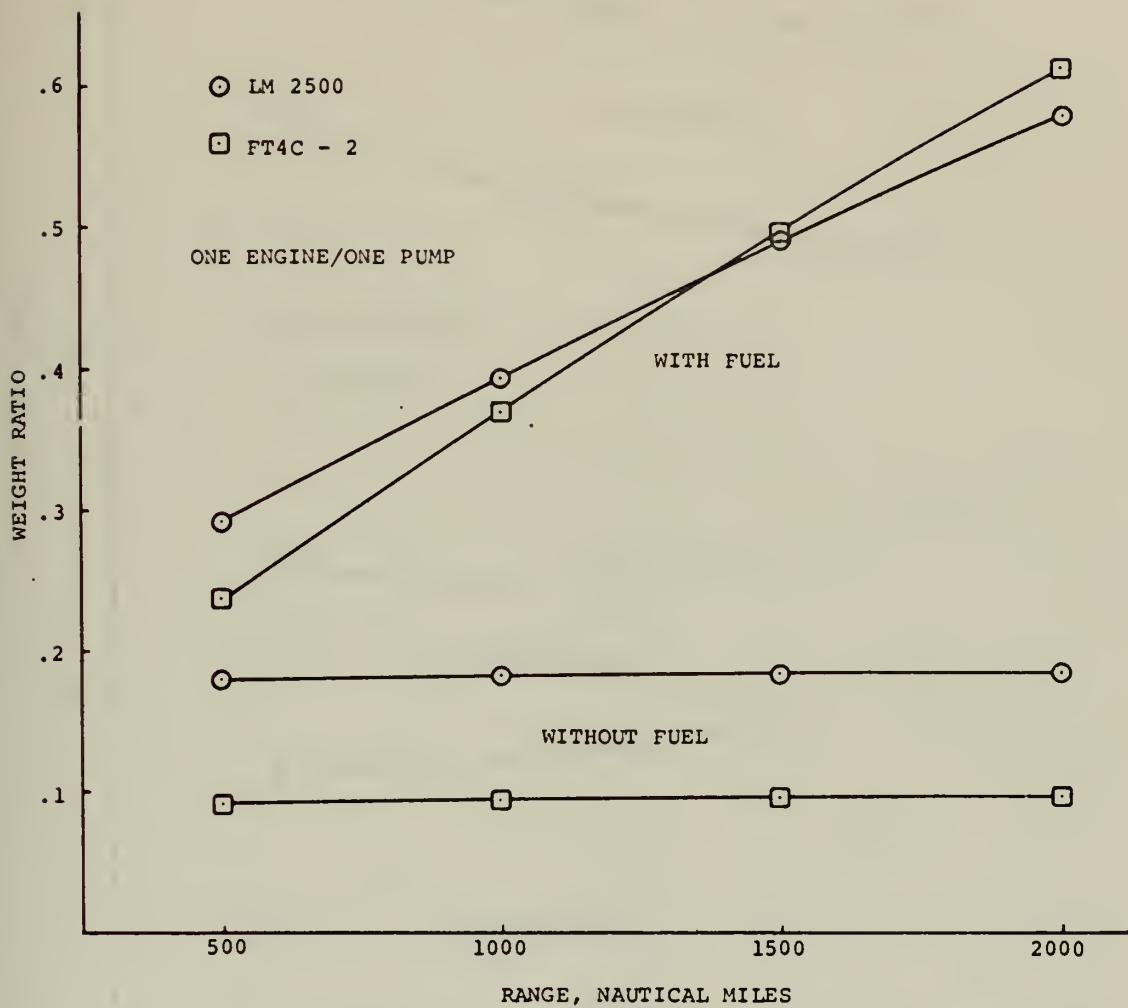


FIGURE 4

WEIGHT RATIO VS RANGE

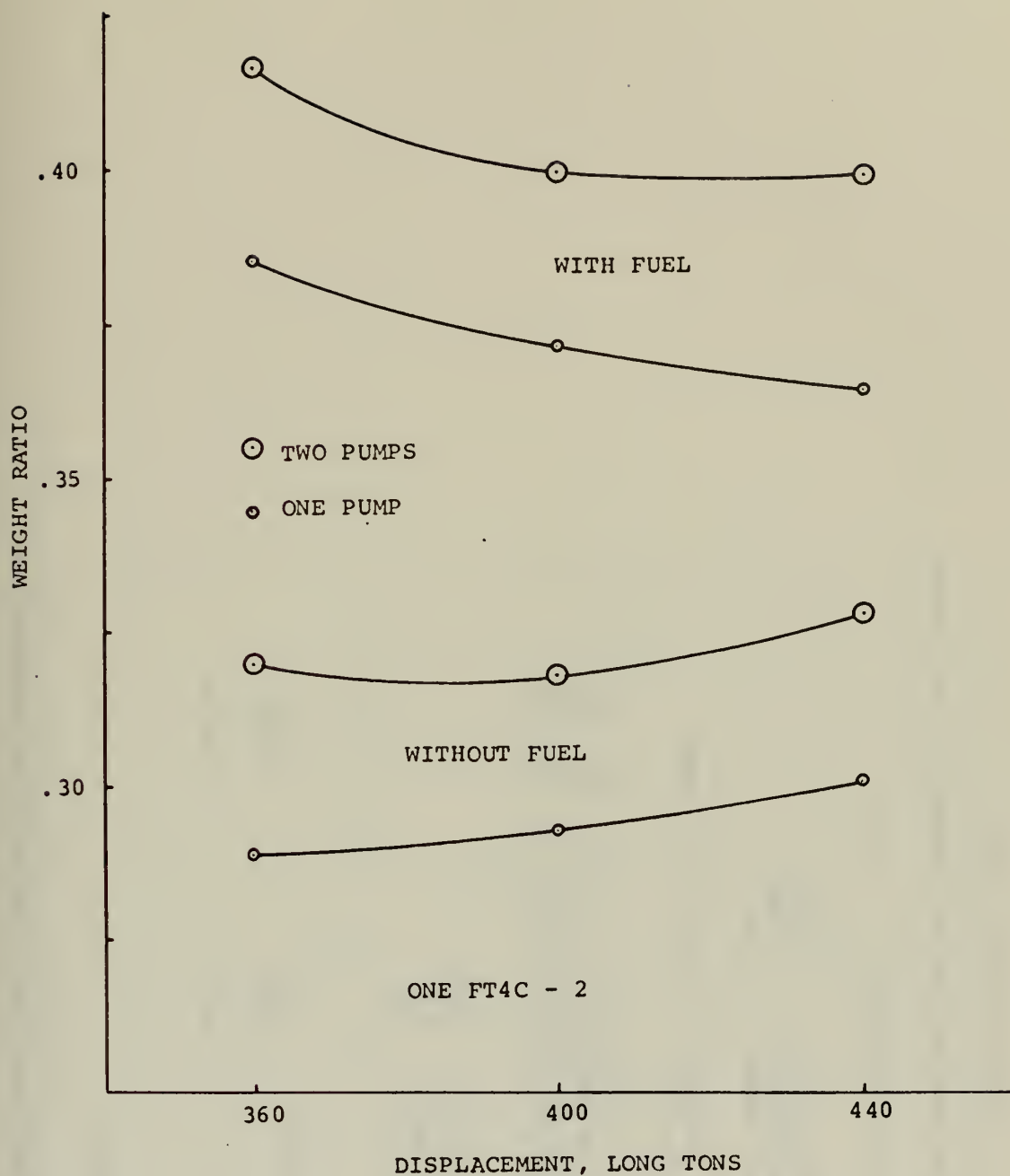


FIGURE 5
WEIGHT RATIO VS DISPLACEMENT

CRAFT CHARACTERISTICS

OPERATIONAL

	CRUISE	TAKE-OFF
VELOCITY, KNOTS	42.0	21.0
TOTAL DRAG, LBS	79250.	101204.
ANGLE OF ATTACK, DEGREES	0.0	2.0

CONFIGURATION

AVERAGE BEAM, FEET.....	42.0
DISPLACEMENT, LONG TONS....	400.
ENDURANCE, NM.....	1000.
1 GAS TURBINE PLANT.....	FT4C-2

DEPTH OF SUBMERGENCE OF NACELLE.....	5.0	FEET
HEIGHT OF PUMP CENTERLINE ABOVE MEAN WATER.....	10.0	FEET
HEIGHT OF PUMP CENTERLINE ABOVE KEEL.....	2.0	FEET
DISTANCE OF STRUT FROM TRANSCM.....	20.0	FEET
DISTANCE OF PUMP EXIT FROM TRANSCM.....	20.0	FEET

WATER PROPERTIES
(ASSUMES STANDARD(3.5% SALINITY) SALT WATER)

TEMPERATURE, DEGREES FAHRENHEIT	59.
DENSITY, LBF-SEC**2/FEET**4	1.989
VISCOSITY, *10**5, FEET**2/SEC	1.279
VAPOR PRESSURE, FEET	0.545

ACCELERATION OF GRAVITY, FT/SECS**2	32.174
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NO EQUIPMENTS OR CONFIGURATIONS SPECIFIED. GENERATED AS PER PROGRAM

FIGURE 6 SAMPLE OUTPUT DATA

*** SYSTEM HEIGHT IS 148.20 TONS ***

NUMBER OF GAS TURBINES IS 1
NUMBER OF PUMPS IS 1

*** WATERJET PROPULSION SYSTEM OUTPUT DATA ***

INLET AREA, TOTAL, FEET**2 7.90
STRUT DIFFUSER AREA RATIO 1.71
JET AREA, TOTAL, FEET**2 1.64

FLOW RATE CFS	JET VELOCITY	JET RATIO	INLET VELOCITY	INLET RATIO	SHP PER TURBINE	PROPULSIVE COEFFICIENT	CRUISE T/O
321.57	196.27	2.77	40.76	0.57	23472.	0.4379	
354.45	216.07	6.10	42.56	1.20	34549.	0.1891	

-42-

RADIUS RATIO	DUCT RADIUS	ANGLE DEGREES	LOCATION	SHAPE	CRUISE DUCT LOSSES (FEET)	T/O DUCT LOSSES (FEET)	EVALUATION DUCT LOSSES (FEET)
1.50	1.76	90.00	STRUT	RECTANGLE			
1.50	1.15	90.00	HULL	RECTANGLE			
1.50	1.83	90.00	PUMP	CIRCLE			
NACELLE	1068.2	0.0			2.26	2.30	
STRUT ELBOW	816.0	0.0			2.09	2.47	
STRUT DIFFUSER	5603.8	14956.8			0.33	0.39	
HULL ELBOW	1048.1	3658.9			0.82	0.97	
ATHWARTSHIPS LENGTH	4593.8	21413.7			0.14	0.17	
PUMP ELBOW	1787.7	5837.8			0.31	0.37	
FORE AND AFT LENGTH	0.0	0.0			0.00	0.00	
PUMP	10310.4	5670.7					
NOZZLE	360.4	1222.2			1.08	1.33	
REDUCTION GEAR	1487.5	0.0					
FUEL	0.0	249093.4					
FT4C-2	14200.0	0.0					
JET LIFT	0.0	-11152.7					

TOTALS	41265.8	290700.6			7.03	8.00	

FIGURE 6 SAMPLE OUTPUT DATA (CONT.)

PUMP DATA

CLNTRIFUGAL PUMP WITH 10 COUBLE SUCTION IMPELLERS PER PUMP

HEAD	NPSH	THOMA	RPM	EFFICIENCY	CRUISE
537.6	94.7	0.176	1275.3	0.876	T/O
724.0	35.4	0.049	1462.8	0.882	

SPECIFIC SPEED,CFS.....	44.1
SUCTION SPECIFIC SPEED,CFS.....	424.5
FLW CUEFFICIENT.....	0.140
HEAD CUEFFICIENT.....	0.596
INLET TIP DIAMETER,FEET.....	1.18
EXIT TIP DIAMETER,FEET.....	2.58
PUMP LENGTH,FEET.....	18.67
GEAR RATIO.....	2.46

NACELLE DATA

1	DIAMETER RATIO,DI/DM.....	0.719
4	MAXIMUM DIAMETER,DM,FEET.....	3.12
3	INLET AREA PER NACELLE,FT**2.....	3.95
1	AUXILIARY INLET AREA PER NACELLE,FT**2	0.22
	FUREBUDDY LENGTH,FEET.....	1.34
	LIP LENGTH,FEET.....	0.15
	DIFFUSER LENGTH,FEET.....	3.87
	NACELLE LENGTH,FEET.....	17.16

STRUT CONFIGURATION

T/C	THICKNESS	CHORD	ROOT	TIP	WATERLINE
0.130	1.7	12.7			
	1.3	9.7			
	1.4	10.9			

DRAG ESTIMATES			
TOTAL	NACELLE	STRUT	SPRAY
79755.3	4092.3	2648.4	2014.7
101389.3	1143.1	742.6	503.7

TOTAL SYSTEM WEIGHT RATIO IS 0.3705

SYSTEM WEIGHT RATIO WITHCLT FUEL IS 0.0925

FIGURE 6 SAMPLE OUTPUT DATA (CONT.)

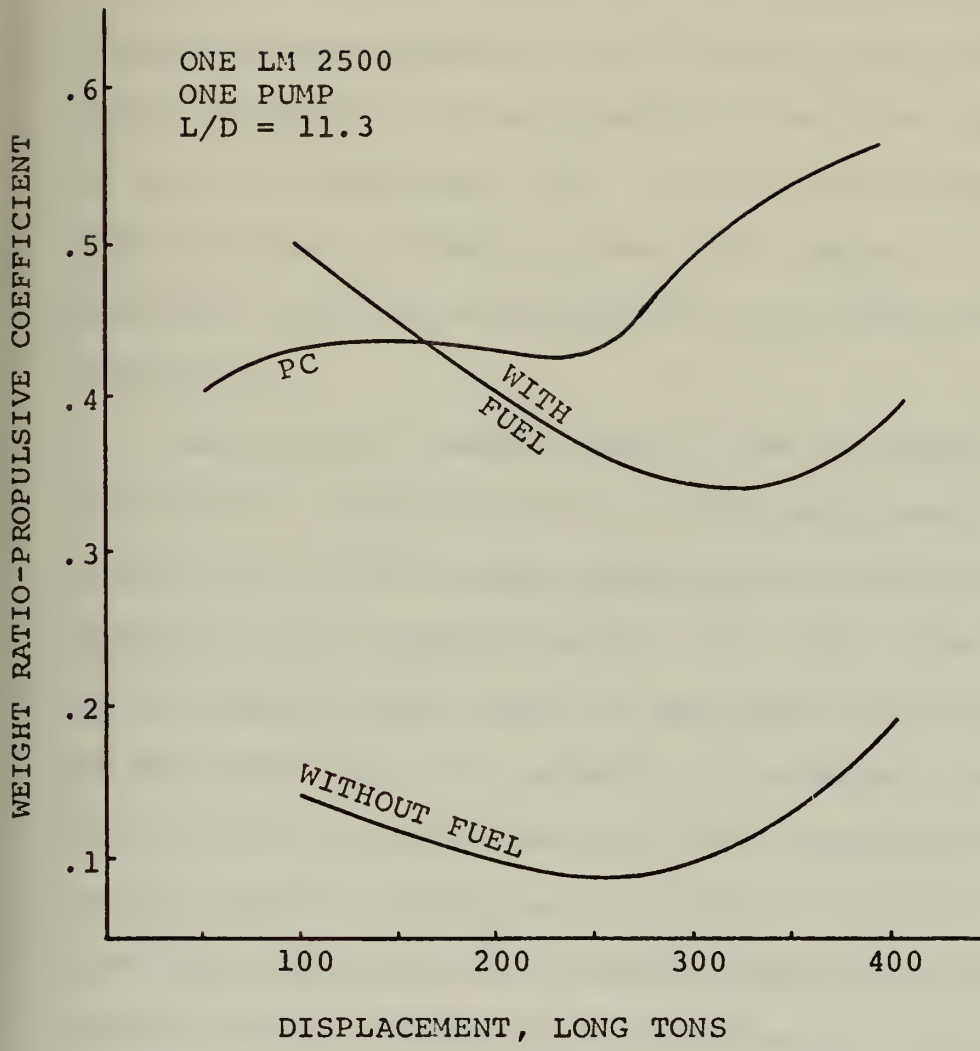


FIGURE 7 WEIGHT RATIO/PROPULSIVE
COEFFICIENT VS DISPLACEMENT

APPENDIX A - OPTIMIZATION

The selection of an optimization procedure represents a key consideration in the overall design method. For one thing it may require computations to be made solely for its usage, as in gradient methods. Then, too, it may require a supervisory program to tell it what to do, as in random search techniques, or an adaptive direction capability may be self-contained (ref. 18). It is not the intent of this investigation to find or invent the "optimum" optimization procedure, but the significance of its usage should not be minimized.

The general consideration of how to optimize has a wide variety of tools to aid in the achievement of the answer. One of the more common methods utilized is some variant of the gradient search (ref. 19). The rationale is an intuitive one, based on the notion that if the goal is the attainment of a maximum, for example, the quickest way to go is in the direction of the steepest slope. This is not unlike a blind man's method of climbing a mountain. Like the blind man, the gradient search can encounter difficulties by following this philosophy. The assumption of a finite slope in the area of interest not only requires the absence of steps on the hypersurface, but imposes the more stringent limitation that the slope be calculable and containable within the computer. This somewhat limits the types of systems that can be optimized by this technique and

and exacts a stiff penalty for some numerical inaccuracies. Further, assuming that the system to be optimized permits slope calculations, it is not known a priori that such calculations provide sufficient information to compensate for the time spent in making them. In the present system design, discrete steps are virtually guaranteed due to the different pumps and gearboxes used. Since computation of the propulsion system weight is not done by means of an analytic function, slope calculations become as lengthy as the weight calculations themselves. For these reasons, gradient search techniques are rejected as a possible optimization tool for this design problem (ref. 20).

On the opposite end of the optimization spectrum lies the random search. The principal advantages of a random search are the ease with which it may be understood, hence used and programmed, and the simplicity of its computation. No slopes or step sizes need to be calculated or estimated, merely the values of the function at the points of interest. This is also its major disadvantage.

The random search also has no greater likelihood of finding a local optimum than it does of finding the global, and, hence desired optimum. Once the capability of "directionability is gained, local optima are just as likely to be found as the global optimum as is the actual optimum. This is true of all directed searches. The only way to avoid this unpleasant result is to use random starting points

or to use a systematic search over the entire hypersurface. A unimodal surface, of course, does not present this problem.

Since the random search utilizes no other additional information than the function value, it is highly inefficient with the result of greater time spent in the search. All optimization is done in comparison to the previous best. Thus the simplicity of its procedure is gained only at the sacrifice of the large number of evaluations that must be made to assure a reasonably high certitude of attaining the optimum. This becomes especially significant when the time of calculation of a single function value is lengthy. In the design and performance estimation of a propulsion system, a lengthy calculation is likely to be the case, in part due to the iterative loops required (refs. 21, 22).

The solution is clearly somewhere in the middle of these two approaches, utilizing the best features of each and minimizing their disadvantages. It should have the ability to discern direction without the requirement of additional calculations. One such method is the pattern search utilized in this design (ref. 23). The basis of this method is akin to that of the gradient search but is modified in its approach. Again based on intuition, the pattern search depends on the supposition that the search effort should be expended in the direction of improvement. Note that this is a

qualitative judgment rather than a quantitative one, as with gradient methods. The criterion for a sense of direction lies in the success of an evaluation, not in its measure of success, which in itself would be somewhat arbitrary. Thus, while gaining adaptive information about the location of an optimum, the disadvantages of the gradient search are neatly bypassed and the random search is effectively utilized in a more efficient manner.

Following the flow diagram of Figure 8, the pattern search uses the starting point as the initial basepoint. From the basepoint exploratory moves are made. That is, each coordinate is varied from the basepoint position the amount of the step size and the function evaluated at that point. Each exploratory move is examined for possible improvement in the function value. If improvement cannot be made in any direction, the step size is decremented and the exploratory moves resumed from the basepoint. If a position is located with a better function value than the value at the basepoint, the second type of move, a pattern move, is made. A pattern move is a simultaneous change in all dimensions of length equal to the distance from the current basepoint to the present position. If improvement is made in either the pattern move or the sequential exploratory moves, another pattern move is made. Lack of improvement resets the basepoint at the position of the best function value and enters the cycle again with exploratory

moves from the current basepoint.

This ability to seek, find, and establish a pattern gives this search an ability to move rapidly in the best direction. It also has the capability of shifting direction or modifying the pattern when required. Step changes in the hypersurface present little problem since slopes are not utilized. With these features the pattern search can move quite readily along steep ridges or narrow valleys which are common "Waterloos" of other search methods, especially gradient methods.

Perhaps it should be mentioned here that the intent is not to totally degrade the gradient search which has its own attributes and an important usefulness in its own right. It is not without shortcomings, however, that might present a serious detriment to the user who is looking for a generalized search method.

The original form of the pattern search as proposed in reference 23 has been modified to conform to the needs of this design problem. An additional modification has been made that is considered an improvement on the initial scheme. During the exploratory move phase of the search, each dimension was initially incremented by a step size and the function evaluated. If the move was a success, the point and its associated value were saved and the next dimension explored. Lack of success meant decrementing the position by a step size and evaluating the function. Again a success-

ful move was followed by retaining the position and value and exploring the next dimension. An unsuccessful move was ignored and the next dimension incremented. The modification implemented is to vary the dimension first in the direction of the last improvement rather than simply incrementing it. Thus anticipating success, time would be saved by not checking a poor direction. The resulting advantage of this modification is, of course, very dependent on the function being evaluated, but is in keeping with the philosophy of the search and is accomplished at a very small cost of time.

APPENDIX B - NACELLE

The details of this section may be found in reference 9, from which the following comments are drawn.

The selection of the system parameter values sets the ratio of the inlet diameter to the maximum external diameter, DIDM. This effectively limits that maximum amount of diffusion that may be carried out in the nacelle. The present design assumes that the maximum amount of diffusion allowed in the nacelle duct is utilized. The nacelle is first checked to ensure that it does not cavitate externally. Prediction of external cavitation rejects that selection of system parameter values. If cavitation is not predicted, the inlet is checked for cavitation at the point of maximum flow, which generally occurs in the take-off condition. If cavitation was predicted internally, auxiliary inlets are sized to reduce the inflow rate to just below the point of cavitation. The length of the nacelle is then suboptimized to be the length at which the total power loss due to drag and diffusion in the duct is minimized. The total head loss, made up of the lip loss and the diffuser losses may then be calculated. Likewise, the drag coefficient may be calculated from Hoerner's approximation for stramlined bodies (ref. 10), based on wetted surface,

$$C_d = C_{f_s} \left(1 + 1.5 \left(\frac{D_m}{L_n} \right)^2 + 7 \left(\frac{D_m}{L_n} \right)^3 \right)$$

APPENDIX C - ELBOWS

All elbows in the ducting are treated in identical fashion, although individually each elbow may be very different. The inlet and outlet areas for any bend are assumed to be the same. An elbow is considered fully defined by the knowledge of four quantities: width, depth, cross-sectional area, and radius ratio. The radius ratio, $\frac{R}{R_0}$, is the ratio of the radius of the centerline of the bend to the duct radius, as depicted in Figure 9. Since the flow rate, Q , has been previously determined, the first three items are sufficient to calculate the aspect ratio, shape, and the mean velocity of the fluid in the elbow.

For $Re(\frac{R_0}{R})^2 > 91$, Ito's expression for the head loss coefficient in a circular bend is (ref. 11):

$$K_t = .00241 \alpha \theta Re^{-0.17} (\frac{R}{R_0})^{0.84} \quad (C.1)$$

α is a numerical factor dependent on θ and $\frac{R}{R_0}$. For the case of $\theta = 90^\circ$ and $\frac{R}{R_0} < 19.7$

$$\alpha = 0.95 + 17.2 (\frac{R}{R_0})^{-1.96} \quad (C.2)$$

The loss coefficient then is

$$K_t = 0.00241 \theta [0.95 + 17.2 (\frac{R}{R_0})^{-1.96}] Re^{-0.17} (\frac{R}{R_0})^{0.84}$$

For a given duct and considering θ , V , and R constant, partial differentiation of K_t with respect to R_0 leads to

$$\frac{\partial K_t}{\partial RO} = 0 \implies \left(\frac{R}{RO}\right)_{opt} \approx 4.3$$

Since $K_t \approx \frac{C_1}{RO} + C_2 RO$ for these conditions, this result verifies the intuitive feeling that a minimum exists due to a trade-off between friction and bend losses as the number of guide vanes in the elbow varies, as depicted in Figure 10.

If the given radius ratio is greater than one, the losses in the elbow may be reduced by the use of splitters which aid in the prevention of separation. In this context, splitters are defined as guide vanes of unequal length, unequal spacing and possibly unequal curvature (ref. 12). Turning vanes, on the other hand, are always equal in length and curvature, although the spacing between vanes is not necessarily equal. If the splitters are considered in order to subdivide the elbow into smaller elbows, the minimum loss will occur when the ratio of the inside radius to the outside radius of any of the subdivided elbows is constant. Referring to Figure 6, this may be written as

$$\left(\frac{r_i}{r_o}\right)_A = \left(\frac{r_i}{r_o}\right)^{1/n}$$

where n is the number of subdivided elbows, i.e. the number of splitters + 1. Figure 11 depicts a duct with one splitter. Clearly,

$$r_i = R - RO$$

$$r_o = R + RO$$

Hence, the desired radius ratio, 4.3, may be substituted for $\frac{(r_{oa}+r_{ia})}{(r_{oa}-r_{ia})}$ and the resulting equation solved for n, or,

$$n = \frac{\text{Ln} \left[\frac{\frac{R}{RO} - 1}{\frac{R}{RO} + 1} \right]}{\text{Ln} \left[\frac{4.3 - 1}{4.3 + 1} \right]} = 2.12 \text{ Ln} \left[\frac{\frac{R}{RO} + 1}{\frac{R}{RO} - 1} \right] \quad (\text{C.4})$$

The number of splitters determines the spacing. The head loss coefficient may be calculated for each subdivided elbow and the results averaged over the area which will yield the average head loss coefficient for the elbow.

For $\frac{R}{RO} < 1$, equation C.4 has no meaning. For this case the total head loss coefficient was computed as the sum of the friction loss coefficient and the loss coefficient from Figure 12 which is an empirical graph for thin, circular arc turning vanes from reference 12.

In either case the results are valid up to a Reynolds number below that expected in this design. The head loss coefficient including friction is then corrected for the higher Reynolds number by (ref. 13)

$$K_2 = \frac{\chi_2}{\chi_1} K_1$$

where by curve fit,

$$\chi = 1.0057 - 0.16892 \ln(\text{Re} \times 10^{-5}) + 0.0145885 [\ln(\text{Re} \times 10^{-5})]^2 - 0.0016948 [\ln(\text{Re} \times 10^{-5})]^3 \quad (\text{C.5})$$

APPENDIX D - STRUT

The head losses in the strut diffuser are caused by friction and the area expansion which thickens the boundary layer. The friction coefficient is computed in the same manner as for straight pipe. The expansion loss coefficient is

$$K_e = C(1 - \frac{A_i}{A_o})^2 \quad (D.1)$$

C is dependent on the diffuser equivalent angle, 2θ , and is interpolated from the graph in Figure 13, which is for a two-dimensional, straight-walled diffuser. For the flow area, the thickness to chord ratio of the strut is held constant while the area is increased. Hence the assumption of two dimensional diffusion is not strictly valid but is considered a conservative estimate.

The strut dissipates energy externally by a drag term attributable to the body and a term resulting from the spray. The drag coefficient from Hoerner (ref. 10) is based on the planform area and is approximated by

$$C_{ds} = 2C_{fs} [1 + 2(t/c) + 60(t/c)^4] \quad (D.2)$$

The spray drag coefficient, likewise based on planform area is

$$C_{dsp} = .03(t/c) \quad (D.3)$$

This approximation is valid for Froude number, based on the chord length, greater than three (ref. 14).

APPENDIX E

Pump Inlet Piping

The ducting from the hull elbow to the pump inlet is a straight pipe, a 90° elbow and a transition piece. The length of the straight pipe depends on the number of prime movers. In equation form,

$$\text{Length} = \frac{\text{Beam}}{\text{Number of prime movers} + 1}$$

The transition piece is shaped according to the number of pumps under consideration. Since there are two struts ducting water into the hull, assuming a canard foil arrangement, and only one, two, or four pumps are considered, the transition piece will be a junction, straight pipe, or diverging branch.

All straight pipe loss calculations are made using the standard Darcy-Weisbach equation

$$h = fL \frac{V^2}{D_e 2g} \quad (\text{E.1})$$

The Moody friction factor, f , is computed using the closed form approximation of Techo et al (ref. 15),

$$f = [0.86859 \ln(\text{Re}/1.964 \ln(\text{Re}) - 3.8215)]^{-2} \quad (\text{E.2})$$

R_e is based on the mean hydraulic diameter which is defined as

$$D_e = \frac{4A}{P} \quad (\text{E.3})$$

This approximation for the friction factor is accurate to within .1% over the range of Reynolds number from 10^4 to

2.5×10^8 .

For both the junction and divergence, the average velocity is assumed to be the same before and after the transition piece and the piping is symmetrical about the single pipe as shown in Figure 14. This requires that the smaller piping cross-sectional area is 1/2 that of the larger piping.

The mixing loss coefficient in the junction, without friction loss, is computed from

$$K_j = 1 + \lambda - 2\cos(f(\phi)) \quad (E.4)$$

where $f(\phi) = 1.4\phi - .00583\phi^2$

and ϕ is the angle the small branch makes with the larger duct (ref. 16). In the cases examined for this design, ϕ was set to zero resulting in only friction losses in the junction.

The divergence loss factor λ was computed from Figure 15 which is adapted from reference 16. The angle of the divergence, of course, depends on the pump length. It should be noted that the divergence configuration requires another elbow, equal in angle to that of the divergence, to enter the pump.

In all three transition pieces the size was set as required, depending on the pump length. If the pump's length requires a zero or negative transition piece length, the transition piece is neglected and the losses computed only for the athwartships length and the pump elbow

which turns the ducting aft.

APPENDIX F

Pump

The details of this appendix may be found in reference 17, from which the following comments are drawn.

There are two basic types of pumps considered in this design: a multistage, double impeller centrifugal design and an axial pump with an inducer impeller. The variations occur in the number of stages used. The pump design utilizes the flow rate and Thoma's criterion is defined as

$$\sigma = \frac{\text{NPSH}}{\text{Pump Head}} \quad (\text{F.1})$$

where the net positive suction head,

$$\text{NPSH} = \frac{V_o^2}{2g} + h_a - h_v - h_{\text{elev}} - \Delta h_i \quad (\text{F.2})$$

and

$$\text{Pump Head} = \frac{V_j^2 - V_o^2}{2g} + h_{\text{elev}} + \Delta h_t \quad (\text{F.3})$$

The axial pump's first stage is an inducer impeller with up to two additional stages available if the amount of head is sufficiently high. Assumption of a specific speed yields the design pump speed and approximation to the off-design pump speed, which in this case is the cruise condition since the pump is basically designed for take-off conditions. The RPM of the prime mover determines the gear ratio and calculation of the shaft horsepower permits an estimation of the gear weight. Finally, a fuel weight may be calculated for the range specified in

the cruise condition.

The centrifugal pump is designed in the same way except that the number of double suction impellers is increased, thus increasing the RPM, until the combined weights of the pump, dry and wet, gearbox and fuel are at a minimum.

The two resulting pump designs are then compared on the total pump, fuel, and gearbox weights and the least weight system is selected for the propulsion plant.

APPENDIX G

Nozzle

For the purpose of calculation the nozzle was considered a straight-walled nozzle. Assuming the losses are of the form

$$h_n = f \frac{L}{D} \frac{V^2}{2g} \quad (G.1)$$

and noting the friction factor is approximately constant and the velocity essentially uniform, this may be written

$$\Delta h_n = f \frac{\Delta L}{D} \frac{V^2}{2g}$$

or

$$h_n = f \int_0^{L_j} \frac{1}{D} \frac{V^2}{2g} dL$$

Substituting $D = D_j + L \tan(\psi)$

$$V = \frac{4Q}{\pi D^2}$$

results in

$$h_n = f \frac{L_j/2}{D_t - D_j} \left[1 - \frac{16}{(1 + D_t)^4} \right] \frac{V_j^2}{2g} \quad (G.2)$$

which is used for the head loss estimation in the nozzle when $D_t > D_j > 1$, (ref. 2). When $D_j < 1$, the head loss is assumed to be 1.5% of the dynamic head.

In the event that the distance of the pump exit from the transom is greater than 2 times the height of the pump centerline above the keel, the nozzle is assumed to exit through the underside of the craft. The latter distance

is that if the nozzle were directed along an axis at 45° from the vertical.

In every instance, however, the nozzle is assumed to be depressed at the optimum angle to reduce the lift required which would allow the use of smaller foils and hence reduce drag. As before,

$$T = \rho Q(V_j \cos(\beta) - V_o) \quad (1)$$

Rewritten this is also

$$T = (W - T_v) \frac{D}{L} \quad (G.3)$$

where

$$T_v = \rho Q V_j \sin(\beta)$$

Equating equations (1) and (G.3), and solving for V_j gives

$$V_j = (\rho Q V_o + \frac{WD}{L}) [\cos(\beta) + \frac{D \sin(\beta)}{L}]^{-1}$$

The minimum energy input to the jet occurs when V_j is at a minimum, or,

$$\frac{\partial V_j}{\partial \beta} = 0 \Rightarrow \frac{(\rho Q V_o + \frac{WD}{L})(\frac{D \cos(\beta)}{L} - \sin(\beta))}{(\cos(\beta) + \frac{D \sin(\beta)}{L})^2} = 0$$

$$\Rightarrow \beta = \text{TAN}^{-1} \left[\frac{D}{L} \right] \quad (G.4)$$

which is the optimum angle for nozzle depression (refs. 4,6).

PATTERN SEARCH IS AN
OPTIMIZING SUBROUTINE
USING NO DERIVATIVES.
REF: HOOKE &
JEEVES, JACM, APRIL
1961, PP 212-229.

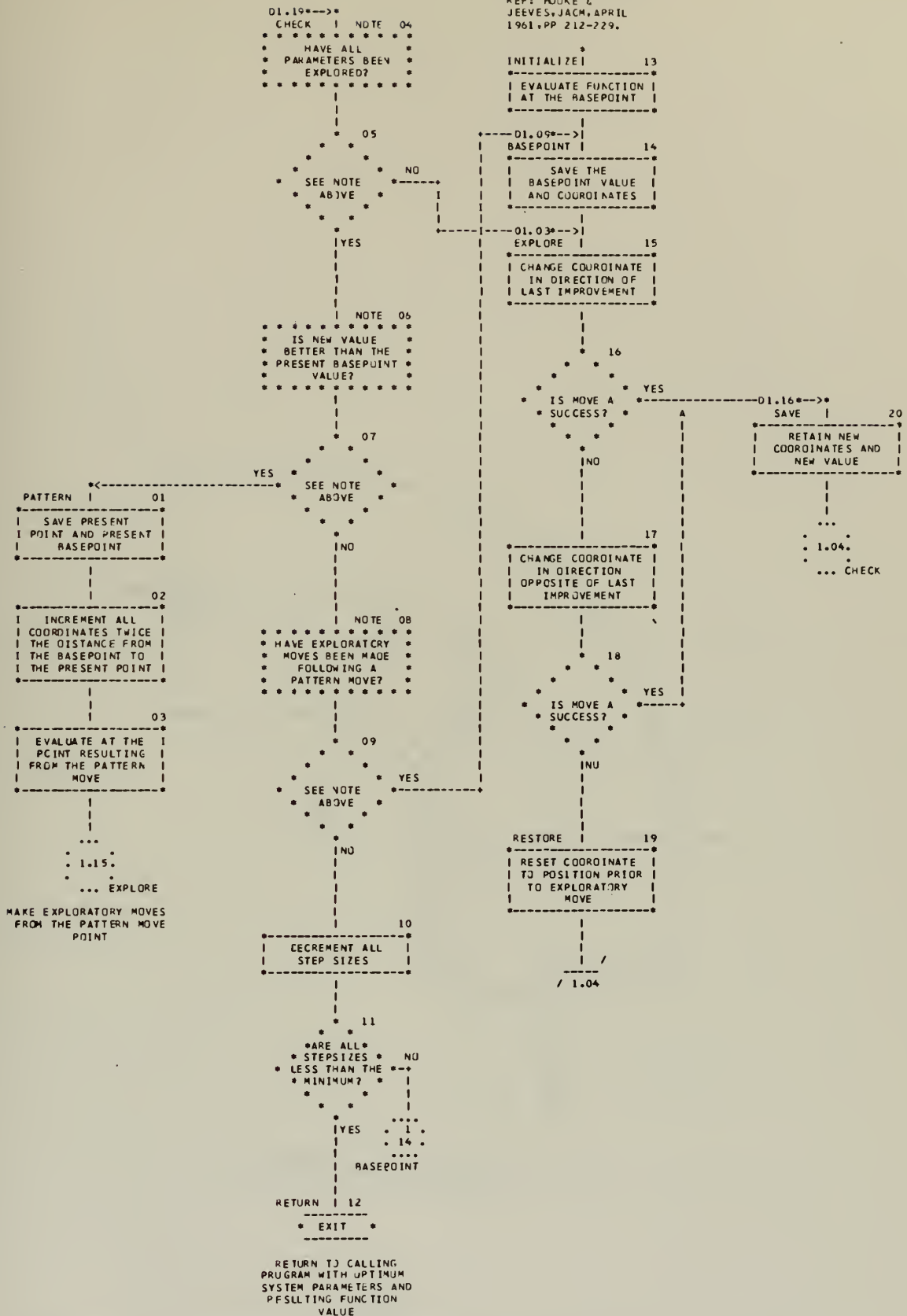


FIGURE 8 GENERALIZED PATTERN SEARCH FLOW DIAGRAM

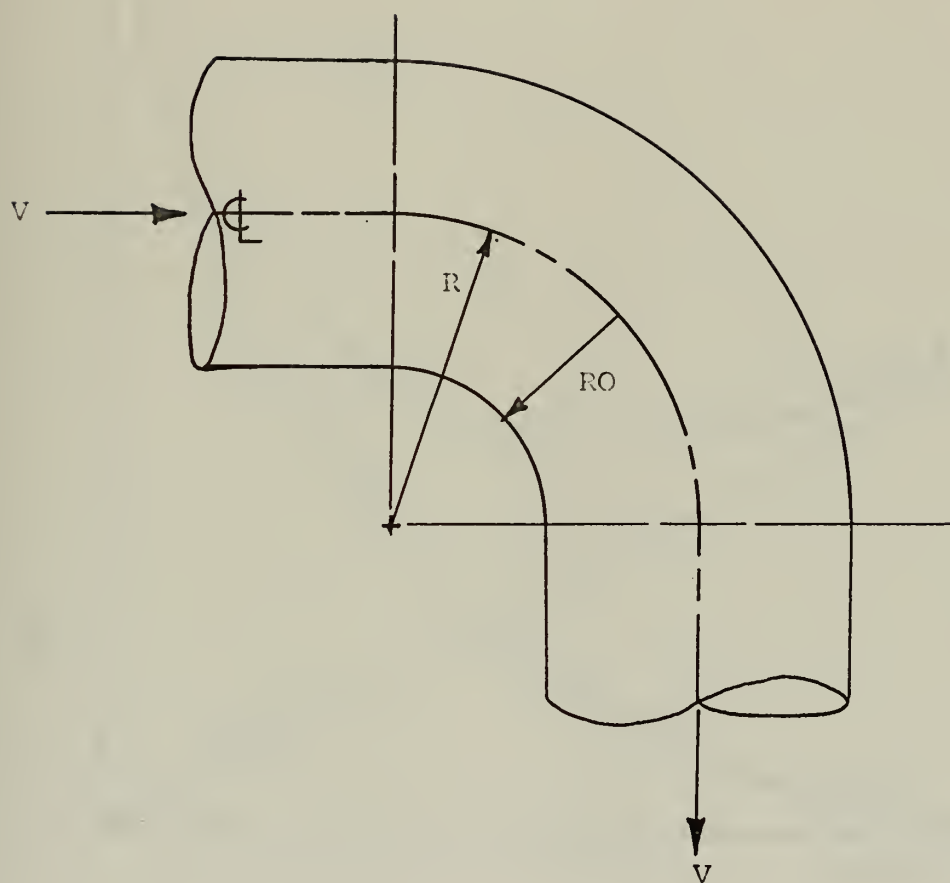


FIGURE 9 . ELBOW

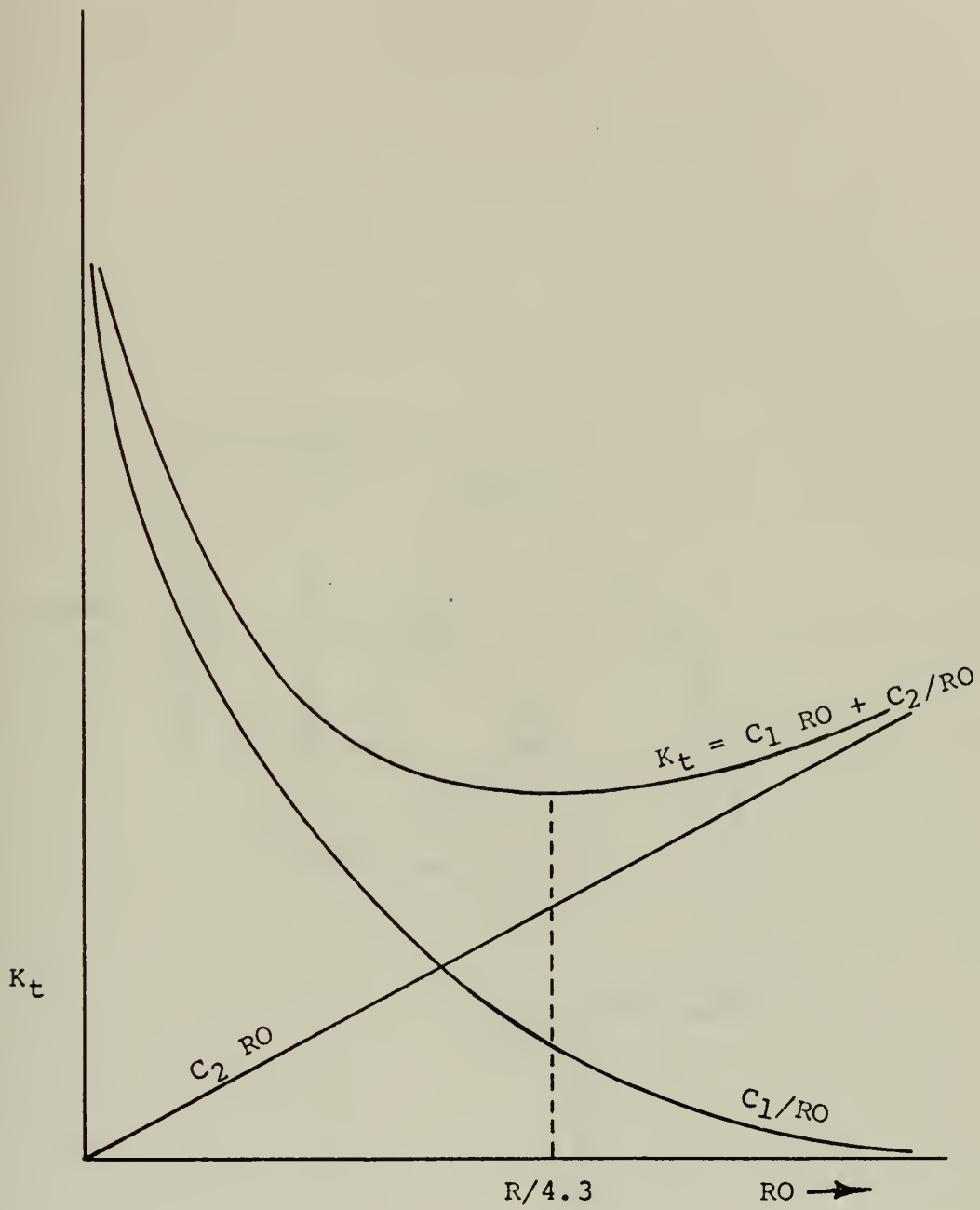


FIGURE 10 MINIMUM ELBOW LOSS COEFFICIENT

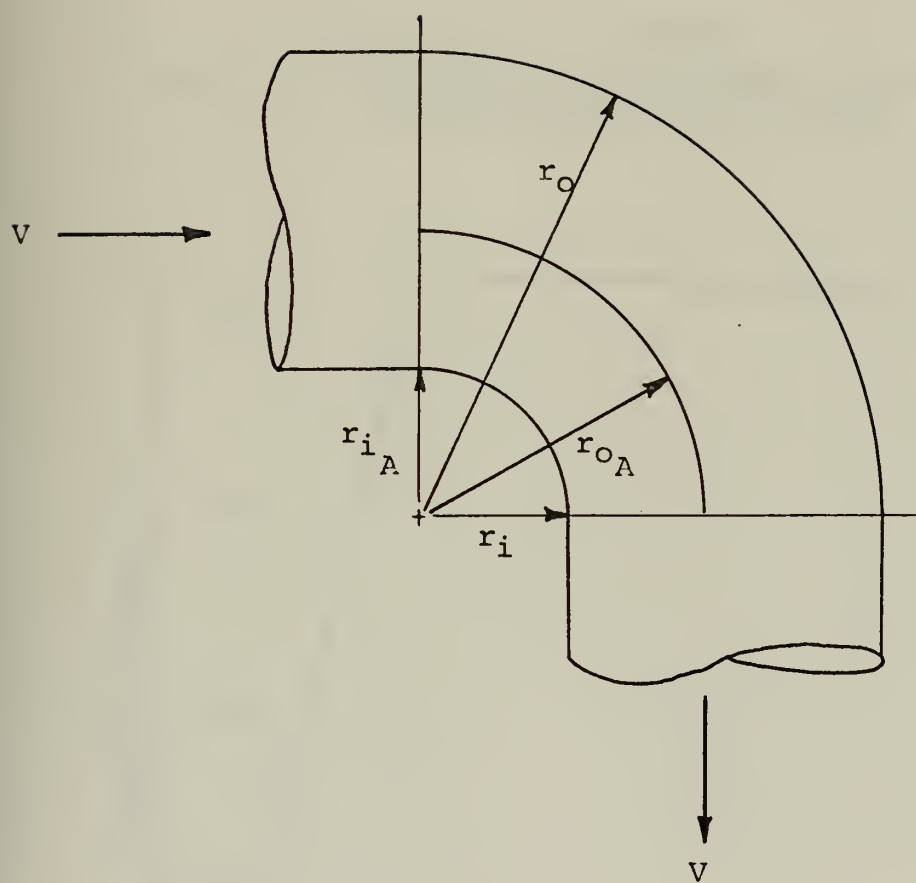


FIGURE 11 ELBOW WITH ONE SPLITTER

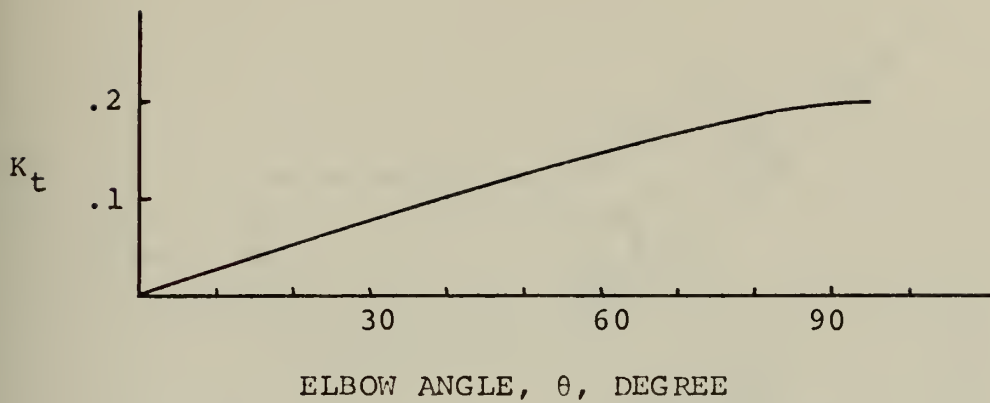


FIGURE 12 ELBOW LOSS COEFFICIENT WITH THIN, CIRCULAR-ARC TURNING VANES

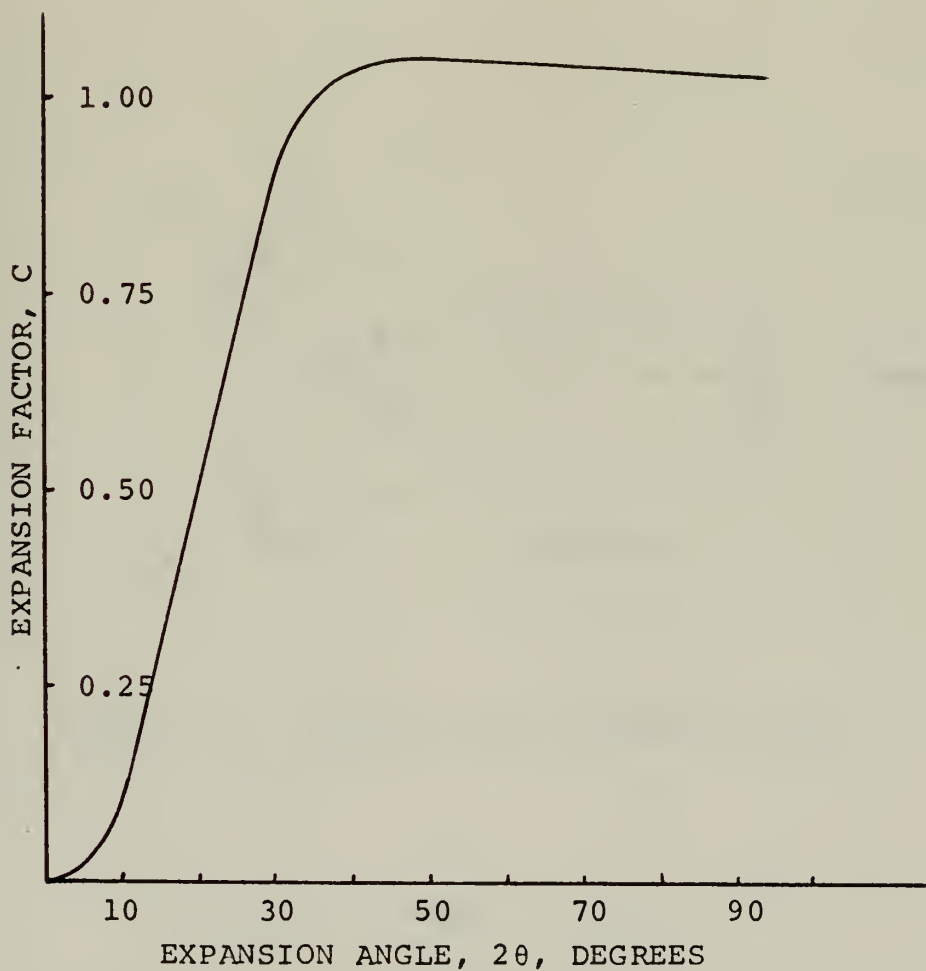


FIGURE 13 EXPANSION FACTOR FOR STRAIGHT WALLED, TWO- DIMENSIONAL DIFFUSER

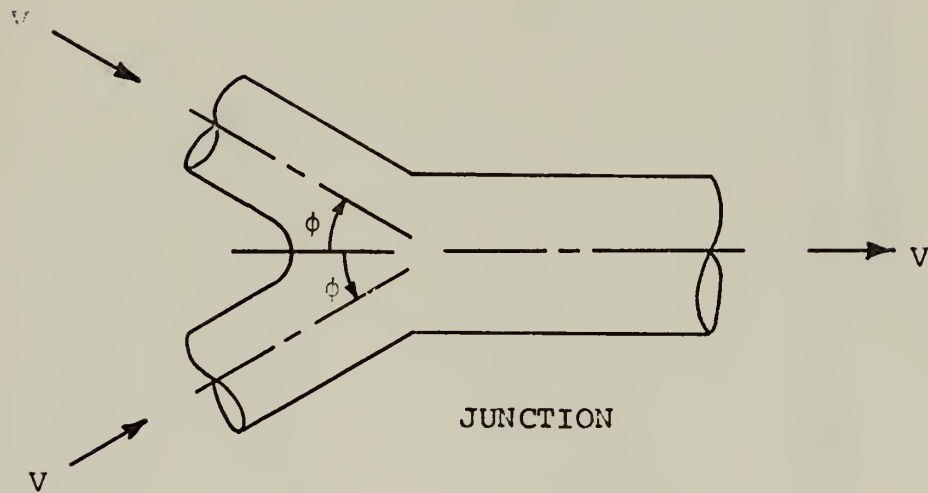
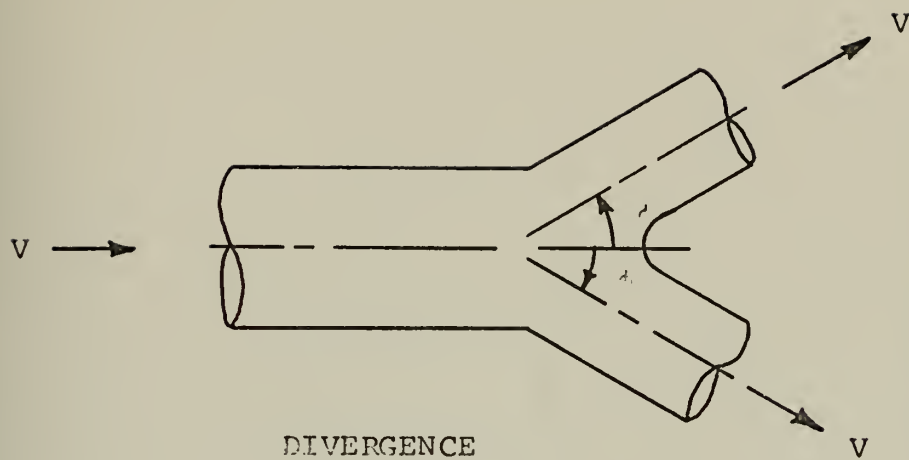


FIGURE 14 JUNCTION AND DIVERGING DUCTS

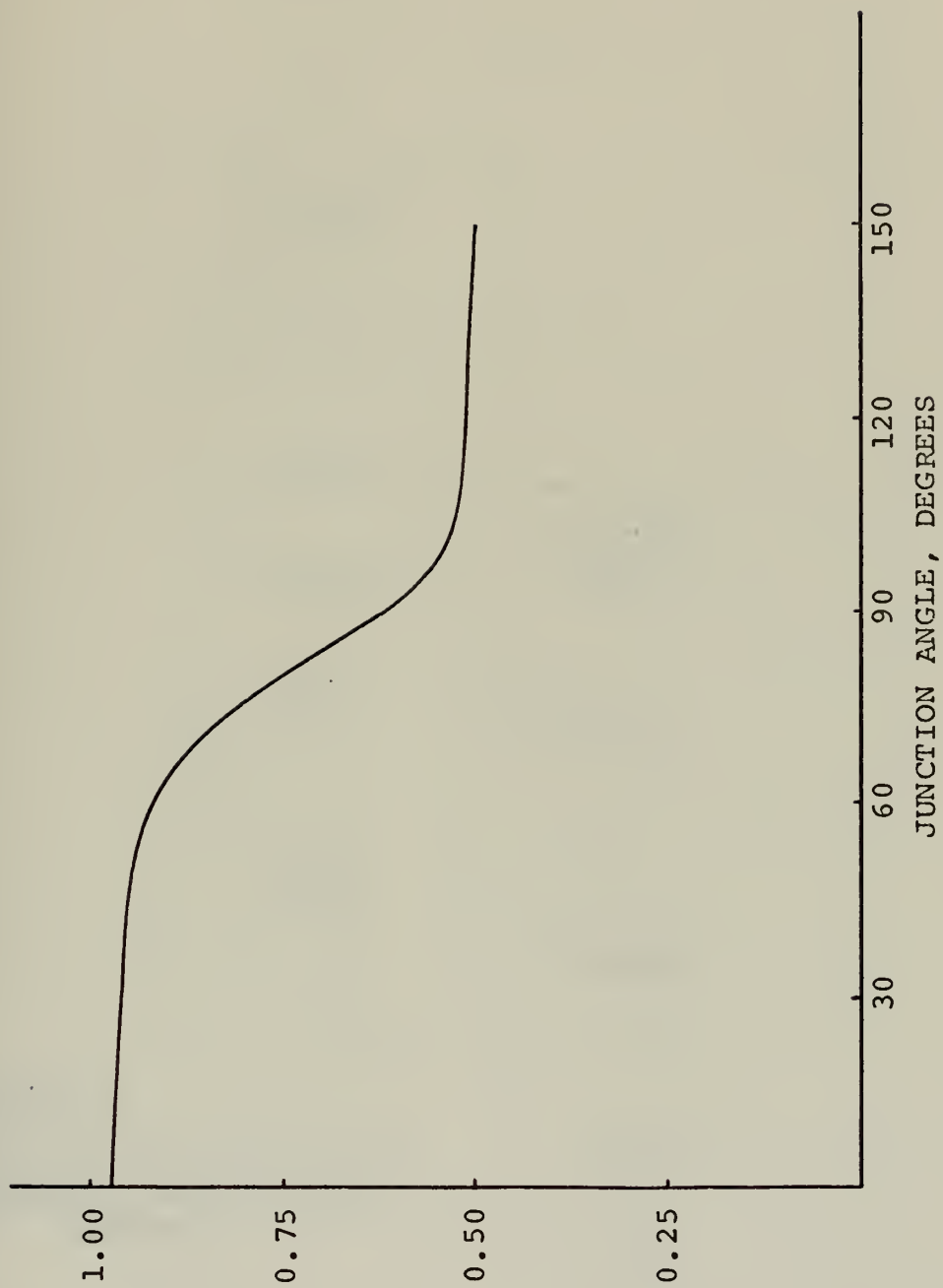


FIGURE 15 JUNCTION LOSS FACTOR, λ

FIGURE 16 IS THE
OPTIMIZATION
EXECUTIVE PROGRAM. IT
INITIALIZES THE
OPTIMIZATION
PROCEDURE AND OUTPUTS
THE INPUT DATA

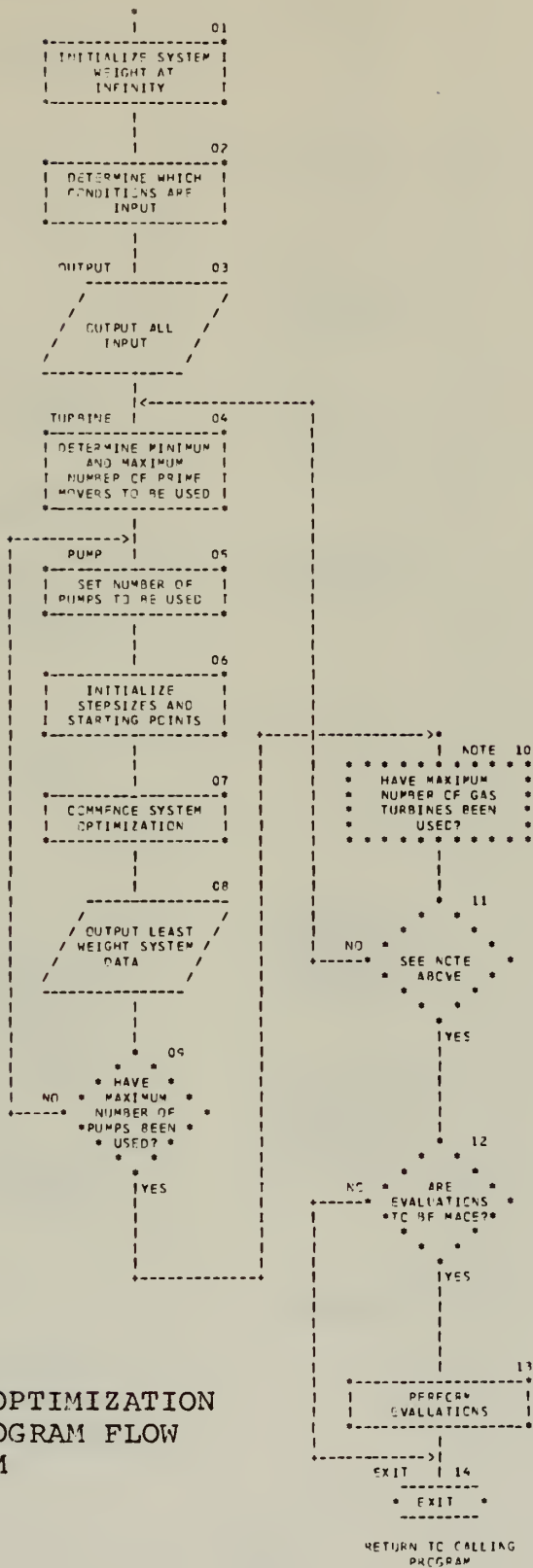


FIGURE 16

GENERALIZED OPTIMIZATION EXECUTIVE PROGRAM FLOW DIAGRAM

FOR NOTE AS SYSTEM
WEIGHT ESTIMATION
EXECUTIVE PROGRAM AND
IS CALLED BY PTPON

NOTE 01
• ARE SYSTEM
• PARAMETER BOUNDS
• EXCEEDED?

02
• YES
• SEE NOTE
• ABOVE
• NO
• 2
• 26
• EXIT

03
INITIALIZE DIMMY
DRAGS

04
CALCULATE JET AND
INLET VELOCITIES

05
ANGLE
COMPUTE OPTIMUM
NOZZLE DEPRESSION
ANGLE

06
• ARE L/O
• BOUNDS
• EXCEEDED?
• YES
• NO
• 2
• 26
• EXIT

07
CALCULATE FLOW
RATES, INLET
VELOCITIES, AND
JET VELOCITIES
FOR ALL
CONDITIONS, AND
ALSO CALCULATE
INLET AND JET
AREAS

08
NACEL
SIZE NACEL,
CALCULATE DRAG
AND HEAD LOSS

09
• WILL NACELLE
• CAVITATE?
• YES
• NO

10
SET DUCT
DIMENSIONS

11
ELPCW
CALCULATE
REQUIRED NUMBER
OF VANES FOR
STRAIT FLOW AND
RESULTING LOSSES

02.17-->1
12
SIZE STRUT,
CALCULATE DRAGS
AND HEAD LOSS

NOTE 13
• CC NEWLY COMPUTED
• DRAGS DIFFER MORE
• THAN 5% FROM THE
• PREVIOUS DRAG
• ESTIMATE?

14
• YES
• SEE NOTE
• ABOVE
• NO

15
ELPCW
SIZE HULL ELBOW
AND ESTIMATE
NUMBER OF VANES
REQUIRED AND
RESULTING HEAD
LOSS

16
DETERMINE PROPER
DLECTING FROM HULL
ELBOW TO PUMP
INLET, CALCULATE
WEIGHTS AND HEAD
LOSSES

17
• IS DUCTING
• CAVITATING?
• YES
• NO
• 2
• 12
• STRUT

18
/ 2.19

02.17-->1
18
DETERMINE
PLACEMENT OF
NOZZLES AND HEAD
LOSS THEREFROM

NOTE 19
• IS THROAT
• DIAMETER LESS
• THAN JET
• DIAMETER?

20
• YES
• SEE NOTE
• ABOVE
• NO

PUMP
21
DETERMINE PUMP
TYPE, GEARBOX
REQUIRED, AND
FUEL USEC

22
SUM SYSTEM
WEIGHTS,
CALCULATE SYSTEM
CENTERS OF
GRAVITY

NOTE 23
• IS TOTAL SYSTEM
• WEIGHT GREATER
• THAN CRAFT
• DISPLACEMENT?

24
• NO
• SEE NOTE
• ABOVE
• YES

25
RESTORE PREVIOUS
DRAG ESTIMATES

07.02-->1
EXIT 26
• EXIT •

RETURN TO CALLING
PROGRAM

FIGURE 17

GENERALIZED WEIGHT
ESTIMATION EXECUTIVE
PROGRAM FLOW DIAGRAM

LIST OF SYMBOLS

USED IN COMMON

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
PARMS			System parameters
	VJVO		Jet velocity ratio
	VIVO		Inlet velocity ratio
	DIDM		Inlet diameter to maximum nacelle diameter ratio
DRAG			Drag estimates
	TDRAG(I)	I	Total craft drag at condition I, pound force
		1	Cruise condition
		2	Take-off condition
		3-5	Evaluation conditions
	STRTD(I)		Strut drag at condition I, pound force
	POD(I)		Nacelle drag at condition I, pound force
	SPRAY(I)		Spray drag at condition I, pound force
	REST(I)		TDRAG(I)-SPRAY(I)-STRTD(I) -POD(I), pound force
	VO(I)		Craft velocity at condition I, foot per second
	TRIM(I)		Craft trim angle at con- dition I, degree
FLOW			Flow characteristics
	Q(I)		Volume flow rate at con- dition I, cubic foot per second

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
	AIN		Inlet area, square foot
	AJET		Jet area, square foot
	AREA(ICOMP)		Ducting cross-sectional area at station ICOMP, square foot
	VJ(I)		Jet velocity at condition I, foot per second
	VI(I)		Inlet velocity at con- dition I, foot per second
ELBW			Elbow data
	XK(IELB)	IELB	Radius ratio of elbow IELB
		1	Strut elbow
		2	Hull elbow
		3	Pump elbow
		4	Divergence elbow
	RO(IELB)		Duct radius at elbow IELB, foot
	THATA(IELB)		Angle of bend of elbow IELB, degree
	WIDTH		Width of duct at elbow inlet
	DEPTH		Depth of duct at elbow inlet
	TYPE(3,ITYPE)		Contains name of elbow shape ITYPE
CHARS			System characteristics
	WGTS(LS,LC)		Weight of component LC, pound

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
		LS	
		1	Structure
		2	Water (or fuel)
		LC	
		1	Nacelle
		2	Strut elbow
		3	Strut diffuser
		4	Hull elbow
		5	Athwartships length
		6	Pump elbow
		7	Transition piece
		8	Pump
		9	Nozzle
		10	Reduction gear
		11	Fuel
		12	Prime mover
		13	Lift from nozzle depression
		14	Total weight
		15	Spare location
	CGS (LG, LC)		Centers of gravity of component LC, excluding fuel, gearbox, or prime mover, foot
		LG	
		1	Structure vertical center gravity (from keel)

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
		2	Structure longitudinal center of gravity (from transom)
		3	Water vertical center of gravity, (from keel)
		4	Water longitudinal center of gravity, (from transom)
	DELH(I,ICOMP)		Total head loss up to and including component ICOMP at condition I, foot
		ICOMP	Same as defined except
		8	Nozzle head loss only
		9	Total system head loss (including elevation), DELH(I,9)=DELH(I,8)+ DELH (I,7)
		10-15	Spare locations
	CGSX		Total longitudinal center of gravity of system excluding gearbox, prime mover and fuel, from transom, foot
	CGSZ		Total vertical center of gravity of system excluding gearbox, prime mover and fuel, from keel, foot
H2O			Sea water (3.5% salinity) properties
	TEMP		Temperature, degree Fahrenheit
	PV		Vapor head, foot
	RHOW		Density, pound force second squared per foot to the fourth

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
	GNU		Viscosity, foot squared per second
	HA		Atmospheric head, foot
TOLER			
	DELTA		Check for optimum system
PSUB			Pump system
	GERAT(NSTG)		Gear ratio required for pump NSTG
	SHP(I,NSTG)		Shaft horsepower required at condition I for pump NSTG, horsepower
	RPM(I,NSTG)		Axial speed of pump NSTG at condition I, revolution per minute
	PERF(L,IENG)		Prime mover IENG Characteristics (L)
		L	
		1	Maximum normal horsepower at design speed, horsepower
		2	Maximum intermittent horsepower at design speed, horsepower
		3	Specific fuel consumption (SFC) at design speed and maximum normal horsepower, pound fuel per horsepower hour
		4	Design speed, RPM
		5	Prime mover weight, without auxiliaries, pound
	ETAP(I,NSTG)		Efficiency of pump NSTG at condition I

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
		I	Same as defined except
		7	Reduction gear
		6,8	Spare locations
SHIP			Craft characteristics
	DISP		Craft displacement, pound
	RANGE		Endurance, nautical mile
	BEAM		Beam, foot
	HS		Depth of submergence of foil, foot
	HE		Height of pump centerline above keel, foot
	HCL		Height of pump centerline above mean water, foot
	XLS		Distance of centerline of strut root from tran- som, foot
	XLPE		Distance of pump exit from transom, foot
	XLP		Length of pump, foot
NACELLE			Nacelle characteristics
	DRAT		Diameter ratio, DI/DM
	DM		Maximum external diameter, foot
	AI		Inlet area per nacelle, square foot
	AIAUX		Auxiliary inlet area per nacelle, square foot
	ELEXT		Length of forebody, foot
	ELENT		Length of lip, foot

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
	ELAUX		Length due to auxiliary inlet, foot
	ELDIF		Length of diffuser, foot
	ELN		Length of nacelle, foot
CONST			Constants
	PI		3.14159265
	G		Acceleration of gravity, 32.174, foot per second squared
	RHOD		Density of steel, 480, pound per cubic foot
STRTC			Strut characteristics
	TC		Thickness to chord ratio
	T		Thickness at root, foot
	C		Chord at root, foot
	Tl		Thickness at tip, foot
	Cl		Chord at tip, foot
	CFM		Chord at flying waterline, foot
INDEX			Indices for program control
	IEVAL		Design/evaluation index
		<0	Evaluate at IEVAL points, no design
		=0	Design at cruise and take-off conditions only
		>0	Design at cruise and take-off conditions and evaluate at IEVAL points

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
	IEQPT		
		=0	No equipments or configuration entered; total system design/evaluation
		>0	Specific equipments or configuration entered (not yet implemented into program)
	ISTR		Initial program condition
		1	Design and/or evaluate
		3	Evaluate only
	NUMB		Final program condition
		2	Design only
		2+ IEVAL	Design and/or evaluate
	IENG		Prime mover type
		1	TF 35
		2	TF 40
		3	Proteus, 1500 rpm
		4	Proteus, 1000 rpm
		5	Tyne 1A
		6	Tyne 1C
		7	FT12A
		8	LM 1500
		9	LM 2500
		10	FT4A-2C
		11	FT4A-12
		12	FT4C-2

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
	ITYPE		Elbow shape
		1	Ellipse
		2	Circle
		3	Rectangle
		4	Square
	ICOMP		Component index
		1	Nacelle outlet
		2	Strut elbow
		3	Strut diffuser exit
		4	Hull elbow
		5	Athwartships length
		6	Pump elbow
		7	Transition piece
		8	Pump inlet
		9	Nozzle throat
	NPUMP		Number of pumps
	NGT		Number of gas turbines
ITABL			Interpolation parameters
CDRAG			Computed drags
	CSTRT(I)		Computed strut drag at condition I, pound force
	CPOD(I)		Computed nacelle drag at condition I, pound force
	CSPRY(I)		Computed spray drag at condition I, pound force
WEGT			Pump, gear and fuel weights

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
	XWD (NSTG)		Pump NSTG dry weight, pound
	XWW (NSTG)		Pump NSTG wet weight, pound
	XWG (NSTG)		Gearbox weight associated with pump NSTG, pound
	XWF (NSTG)		Fuel weight associated with pump NSTG, pound
PUMM			Pump characteristics
	QQ (I)		Flow rate per pump at condition I, cubic foot per second
	D1S (NSTG)		Inlet tip diameter of pump NSTG, foot
	D2S (NSTG)		Exit tip diameter of pump NSTG, foot
	XNS (NSTG)		Specific speed of pump NSTG, cfs units
	SM (NSTG)		Suction specific speed of pump NSTG, cfs units
	PLP (NSTG)		Length of pump NSTG, foot
	NSTG		Indicator of pump type
		1	Axial pump with single inducer impeller
		2	Axial pump with inducer and one impeller stage
		3	Axial pump with inducer and two impeller stages
		4	Centrifugal pump with max- imum of ten parallel double suction impellers
		5	Spare location

<u>Label</u>	<u>Variable Name</u>	<u>Subscript</u>	<u>Description/Usage</u>
	SHI (NSTG)		Head coefficient of pump NSTG
	XIM		Number of parallel double suction impellers for centrifugal pump
			Number of impellers, not including inducer, for centrifugal pump
HEAD			Pump flow characteristics
	HPP (I)		Pump head at condition I, foot
	HSV (I)		Net positive suction head at condition I, foot
	THOM (I)		Thoma's cavitation index at condition I
	PHI (NSTG)		Flow coefficient of pump NSTG
	WF		Working variable for fuel weight, pound
	WG		Working variable for gear weight, pound
*****			Unlabeled common variables
	IFUEL		Logical variable for fuel calculation
		.TRUE.	Make fuel calculation
		.FALSE.	Do not make fuel calcula- tion

VARIABLES USED IN H2OJT
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
PARM(3)	Working system parameters
ENGN(3,IENGN)	Contains name of engine IENGN for output
EHP(I)	Effective horsepower at condition I, horsepower
DEL(3)	Initial step sizes of system parameters
DELMIN(3)	Minimum step sizes of system parameters
VK(I)	Craft speed at condition I, knot
IPRNT	Print data set reference number
DISPL	Craft displacement, long ton
IN	Estimate of minimum number of gas turbines required to power craft
MAX	Estimate of maximum number of gas turbines needed to power craft
XJ	Working variable for number of gas turbines
IK	Working variable for craft condition I
IL	Working variable for IN
KM	Minimum number of pumps to be used for XJ gas turbines
K1	Maximum number of pumps to be used for XJ gas turbines
WEIGT	Propulsion system weight, long ton
IM	Working variable for prime mover characteristic L
DISPL	Craft displacement, long ton
I	Index for do loops
IJ	Working variable for check on power adequacy
J	Index for do loop

<u>Variable</u>	<u>Description</u>
ISAVE	Working variable for MAX
N	Working variable for output of prime mover type
XMIN	Factor for minimum acceptable prime mover SHP operation
MK	Working variable for prime mover characteristic L

LIST OF VARIABLES USED IN FCT
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
APOD(I)	Difference between present and previous nacelle drag calculations at condition I, pound force
ASTRT(I)	Difference between present and previous strut drag calculations at condition I, pound force
ASPRY(I)	Difference between present and previous spray drag calculations at condition I, pound force
C(I)	Margin factor for thrust at condition I
TSUM	Working variable for propulsion system weight, pound
DSIG	Working variable for SIGMA
TOTAL	Total head less vapor head, foot
SIGMA	Head above vapor head, foot
SUMZ	Working variable for moment in vertical plane, due to weights, foot pound force
SUMX	Working variable for moment in longitudinal plane due to weights, foot pound force
SUM	Working variable for system weights, pound
ZSUM	Total moment in vertical plane due to weights, foot pound force
XSUM	Total moment in longitudinal plane due to weights, foot pound force
SPD	Working variable for jet velocity calculation, foot per second
J	Working variable for NUMB
JDRAG	Indicator of acceptable drag accuracy
1	New drag calculation is within 5% of previous

<u>Variable</u>		<u>Description</u>
		calculation
	2	New drag calculation is greater than 5% of previous calculation, redesign strut and nacelle
ANGLE		Optimum nozzle depression angle, radian
COEF		Factor for nacelle drag calculation
	0	Strut must be resized due to cavitation
	1	Use nacelle design
KOUNT		Working variable for craft condition I
I		Craft condition
PARM(K)		Working variable for system parameters
	K	
	1	VJVO
	2	VIVO
DDRAG(I)		Previous acceptable total drag calculation at condition I, pound force
DSPRY(I)		Previous acceptable spray drag calculation at condition I, pound force
DSTRT(I)		Previous acceptable strut drag calculation at condition I, pound force
DPOD(I)		Previous acceptable nacelle drag calculation at condition I, pound force

LIST OF VARIABLES USED IN NACEL
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
ZK	Percentage of auxiliary inlet area permitting flow
SPO	Static pressure at inlet, pound per square foot
PVP	Vapor pressure, pound per square foot
SIGTV	Incipient turning vane cavitation number, referenced to diffuser exit velocity
JNUMB	Working variable for NUMB
I	Craft condition, also index for do loops
CPEX	Peak external pressure coefficient
K	Working index for do loop for ELEFT/DM values
J	Working index for do loop for VIVO values
XD	Length of forebody to maximum diameter ratio, ELEFT/DM
DIDMX	Maximum permissible diameter ratio
QI	Flow rate per strut, cubic foot per second
DI	Nacelle inlet diameter, foot
CPIN	Peak internal pressure coefficient
QIN	Take-off flow rate per nacelle through inlet, cubic foot per second
QC	Take-off flow rate per nacelle, total, cubic foot per second
QAUX	Auxiliary flow rate required to avoid cavitation, cubic foot per second
KDEX	Counter for iterations on diffuser length
VR	Velocity ratio at take-off condition, based on flow through inlet

<u>Variable</u>	<u>Description</u>
VI2	Inlet velocity at take-off condition, based on flow through inlet
PRL2	Pressure recovery coefficient of lip at take-off
PTI	Inlet stagnation pressure immediately aft of lip at take-off, pound per square foot
SPI	Inlet static pressure immediately aft of lip at take-off, pound per square foot
VIAUX	Inlet velocity in auxiliary inlet, foot per second
PRAUX	Pressure recovery of auxiliary inlet
PTAUX	Stagnation pressure inside auxiliary inlet, pound per square foot
DYP	Net dynamic pressure immediately aft of lip, pound per square foot
PC	Average inlet stagnation pressure of combined flow, pound per square foot
QDIF	Working variable for diffuser flow rate, cubic foot per second
PHI	Equivalent angle of forebody, radian
PHS	Sine of equivalent angle of forebody
X	Length of auxiliary inlet, foot
D2	Diffuser exit diameter, foot
D1	Inlet diameter, foot
ELMAX	Maximum permissible length of diffuser, foot
ELMIN	Minimum permissible length of diffuser, foot
II	Working variable for craft condition I
EL	Working variable for diffuser length, foot
DEL	Working variable for change in diffuser length, foot

<u>Variable</u>	<u>Description</u>
ELD	Working variable for nacelle length, foot
ELL	Working variable for nacelle length, foot
ELFAC	Working variable for excess in nacelle length due to diffuser, foot
DDM	Average diffuser diameter, foot
XKT	Form loss coefficient of diffuser
REL	Reynolds number, based on nacelle length
RED	Reynolds number, based on inlet diameter
DL	Ratio of maximum external diameter to nacelle length
CDRG	Computed drag coefficient
ANGL	Equivalent half angle of diffuser, degree
CDIF	Diffuser expansion factor
POW	Power loss due to drag and duct loss of diffuser, horsepower
POWI	Previous power loss calculation for diffuser length, horsepower
EM	Factor in wetted surface calculation
AEXN	Wetted surface area, square foot
REND	Reynolds number, based on inlet diameter
DDIF	Total pressure loss in diffuser, pound per square foot
PLOSS	Total pressure loss in nacelle, pound per square foot
VAOUT	Average exit velocity, foot per second
SQUAR	Factor in critical velocity calculation
VCRIT	Critical velocity in strut elbow, foot per second

<u>Variable</u>	<u>Description</u>
VMAX	Maximum velocity at nacelle exit, foot per second
RENL	Reynolds number, based on nacelle length
NL(2)	Interpolation parameters
ML(2)	Interpolation parameters
KL(2)	Interpolation parameters
JL(2)	Interpolation parameters
IL(2)	Interpolation parameters
VRT(6)	Data array of velocity ratios
XDT(10)	Tabulated forebody length to inlet diameter ratios
PRLT(6)	Tabulated lip pressure recovery coefficients
SIGI(I)	Free stream cavitation index at condition I
PTO(I)	Stagnation pressure at craft condition I, pound per square foot
XDTT(J)	Tabulated EEXT/DM ratios for trim angle J
CDUMX(K)	Dummy array of peak pressure coefficients for VIVO K
CDUMY(L)	Dummy array of velocity ratios for EEXT/DM L
CD(I)	Drag coefficient at craft condition I
DIDMT(J)	Tabulated DI/DM values for EEXT/DM J
VRTT(J)	Dummy array of velocity ratios for angle of attack (J), internal
DLIP(I)	Lip loss coefficient at craft condition I
QO(I)	Free stream dynamic pressure at craft condition I, pound per square foot
VELR(I)	Inlet velocity ratio at craft condition I

<u>Variable</u>	<u>Description</u>
VRTEX(I)	Same as VRTT(I) but external
VRMAX(I)	Maximum permissible velocity ratio at craft condition I
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

VARIABLES USED IN ELBOW
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
SHAPE(3,ITYPE)	Contains name of shape ITYPE
THETA(J)	Data array of elbow angles
XLOSS(J)	Data array of elbow loss coefficients with thin, circular arc turning vanes
ROA(10)	Outside radius of splitters, foot
RE	Reynolds number of duct
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number
CORR	Function statement, calculates head loss correction factor for different Reynolds numbers
REMAX	Maximum Reynolds number permitted for splitter loss equation
KOUNT	Working variable for craft condition I
IELB	Index indicating which elbow is being designed/evaluated
1	Strut
2	Hull
3	Pump
4	Divergence
FACTR	Factor used in splitter loss calculation
RIN	Inside radius of bend, foot
ROUT	Outside radius of bend, foot
RATIO	Desired radius ratio, 4.3
XN	Number of subdivided elbows required to achieve RATIO=4.3

<u>Variable</u>	<u>Description</u>
N	Number of subdivided elbows used
N1	Number of splitters corresponding to N
SUM	Working variable of sum of head times subdivided elbow area, foot cubed
RIA	Inside radius of subdivided elbow, foot
V	Average velocity, foot per second
HGT	Height of subdivided elbow, foot
AA	Equivalent cross-sectional area of subdivided elbow based on HGT, square foot
RAD	Equivalent radius of subdivided elbow, foot
XCORR	Ratio of head loss correction factors for differing Reynolds numbers
XKT	Head loss coefficient of subdivided elbow
DIAM	Equivalent diameter, foot
VOLV	Volume of splitters, cubic foot
VOL	Volume of splitters and elbow structure, cubic foot
AREAL	Duct area per elbow, square foot
IJ	Working variable for shape determination
IK	Working variable for shape determination
I	Working variable for number of subdivided elbows N
RATEO	Ratio of inside radius to outside radius of subdivided elbows
HEAD	Average head loss in elbow, foot

LIST OF VARIABLES USED IN STRUT
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
THET2	Array of data of equivalent angle of diffuser, degree
EXPAN	Array of data of expansion coefficient
ARATO	Area ratio of strut diffuser
VL	Local maximum velocity, external, foot per second
SIGMA	Local cavitation number, external
CM	Mean chord, foot
DEIN	Strut inlet equivalent diameter, foot
WIDE	Width of duct at strut exit, foot
DEOUT	Strut exit equivalent diameter, foot
DEAVE	Average equivalent diameter, foot
STRT	Vertical strut length, foot
XLONG	Actual strut length, foot
STAN	Arctangent of equivalent diffuser angle
THETA	Equivalent angle of diffuser, 2θ , degree
ECOE	Diffuser expansion factor
FORML	Diffuser expansion loss coefficient
VELIN	Average inlet velocity, foot per second
VLOUT	Average exit velocity, foot per second
RES	Strut Reynolds number, based on mean chord
CDS	Strut drag coefficient
CDSP	Spray drag coefficient
RE	Duct Reynolds number, based on inlet velocity

<u>Variable</u>	<u>Description</u>
PIPEL	Duct friction loss coefficient
TOTAL	Total loss coefficient
HEAD	Head loss of diffuser, foot
KOUNT	Working variable for craft condition I
HGT	Elevation of strut, foot
CGWS	Vertical center of gravity of duct, foot

LIST OF VARIABLES USED IN JUNCT
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
ALPHA	Assumed junction angle of 0° , degree
DIAM	Duct diameter, foot
FRCTL	Friction loss coefficient for athwartships length
KOUNT	Working variable for craft condition I
AJCT	Length of fore and aft ducting to pump inlet, foot
FRCTJ	Friction loss coefficient for junction
XLAMD	Working variable for AMIXL calculation
FLONG	Length of athwartships ducting, foot
AJCTL	Total loss coefficient of junction
AMIXL	Mixing loss coefficient of junction
V	Average velocity, foot per second
XPUMP	Number of gas turbines + 1
RE	Reynolds number of duct
BETA(J)	Data array of junction angles, degree
ALAMD(J)	Data array of mixing loss coefficient corresponding to BETA(J)
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

LIST OF VARIABLES USED IN PIPE
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
KOUNT	Working variable for craft condition I
V	Average velocity, foot per second
DIAM	Duct diameter, foot
RE	Reynolds number of duct
APIPE	Length of fore and aft pipe to pump inlet, foot
FRCTL	Friction loss coefficient for athwartships length
XPUMP	Number of gas turbines
XKT	Friction loss coefficient of fore and aft length
XLONG	Length of athwartships pipe, foot
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

LIST OF VARIABLES USED IN DIVRG
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number
KOUNT	Working variable for craft condition I
RE	Reynolds number of duct
DIVL	Divergence loss coefficient, not including friction
DWGT1	Duct weight of divergence angle, pound
DWGT2	Duct weight of divergence length, pound
DWGT3	Duct weight of pump inlet angle, pound
WWGT1	Water weight of divergence angle, pound
WWGT2	Water weight of divergence length, pound
WWGT3	Water weight of pump inlet angle, pound
CGWX1	Longitudinal center of gravity of divergence angle, from transom, foot
CGWX2	Longitudinal center of gravity of divergence length, from transom, foot
CGWX3	Longitudinal center of gravity of pump inlet angle, from transom, foot
DIAM	Duct diameter, foot
FRCTL	Friction loss coefficient for athwartships length
DIVLC	Total divergence loss coefficient
XPUMP	Number of gas turbines + 1
ANGLE	Divergence angle, also pump inlet angle, radian
HEADL	Total divergence head loss, foot
FLONG	Athwartships length, foot

<u>Variable</u>	<u>Description</u>
XLONG	Fore and aft length, foot
V	Average velocity, foot per second
ADIV	Divergence length, $ADIV = XLONG / \cos(ANGLE)$, foot
THETA(J)	Data array of divergence angles, degree
COEF(J)	Data array of divergence loss coefficients without friction, corresponding to THETA(J)

LIST OF VARIABLES USED IN NOZZL
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
KOUNT	Working variable for craft condition I
XLPS	Dummy nozzle length, foot
XFAC	Check on whether nozzle exits through bottom or stern
XPUMP	Number of pumps
AN0Z	Optimum nozzle depression angle, radian
XLNOZ	Nozzle length, foot
DT	Nozzle throat diameter, foot
DJ	Nozzle jet diameter, foot
XCORR	Nozzle head loss factor
RE	Reynolds number, based on average diameter and velocity
AREAl	Throat pipe area, square foot
AJETl	Jet pipe area, square foot
QQ	Flow rate per nozzle, cubic foot per second
FRICT	Function statement, calculates Moody friction factor for smooth pipe, based on Reynolds number

LIST OF VARIABLES USED IN PUMP
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
K	Cruise condition indicator
J	Take-off condition indicator
I	Index for do loops
XPUMP	Number of pumps
THOMI	Lower limit of Thoma's criterion for single inducer axial pump
DRAT	Hub to tip diameter ratio
XXLP	Factor for pump length
CW	Weight coefficient
QX	Ratio of cruise flow rate to take-off flow rate
CA	Factor for RPM calculation
CB	Factor for RPM calculation
HX	Ratio of design pump head to off design head
RX	Ratio of design to off design pump RPM
PHRAT	Ratio of off design to design flow coefficients
XNGT	Number of gas turbines
ETAPP	Product of pump and gearbox efficiencies
HP	Inducer head for one and two stage axial pump designs, foot
THOMS	Thoma's cavitation criterion for inlet to axial stage
HHP	Axial stage pump head, foot
BETA2	Exit blade angle, radian

<u>Variable</u>	<u>Description</u>
XNNS	Non-dimensional specific speed
BD	Impeller exit width ratio
CC	Factor in flow coefficient calculation
AA	Factor in flow coefficient calculation
IMPL	Maximum number of impellers permitted for centrifugal pump, = 10
M	Working variable for number of centrifugal pump impellers
N	Working variable for NSTG
PC(K,J)	Inducer head curve coefficients
PCA(K,J)	Inducer plus axial stage head curve coefficients
PCC(K,J)	Centrifugal pump head curve coefficients
XRPM(M)	Working variable for off design RPM of centrifugal pump with M impellers, RPM
XD1(M)	Working variable for inlet tip diameter, D1S, foot
XD2(M)	Working variable for exit tip diameter, D2S, foot
RPK(M)	Working variable for design RPM of centrifugal pump with M impellers, square foot
XPUP(M)	Working variable for centrifugal pump area with M impellers, foot squared
YLP(M)	Working variable for centrifugal pump length with M impellers, foot
XERAT(M)	Working variable for gear ratio required for centrifugal pump with M impellers
APUP(NSTG)	Inlet area of pump NSTG, square foot
WRAT(NSTG)	Weight ratio of pump NSTG, including pump dry and wet weight, gearbox and fuel

<u>Variable</u>	<u>Description</u>
WD(M)	Working variable for XWD(NSTG) for centrifugal pump with M impellers
WW(M)	Working variable for XWW(NSTG) for centrifugal pump with M impellers
WWG(M)	Working variable for XWG(NSTG) for centrifugal pump with M impellers

LIST OF VARIABLES USED IN FUEL
NOT IN COMMON

<u>Variables</u>	<u>Description</u>
CFS	Constant for SFC calculation
CA	Cruise condition drag to lift ratio
CD	1 + total system head loss coefficient, based on jet velocity
N	Number of intervals endurance is divided into + 1
XN	Number of intervals endurance is divided into
TI	Time to cover one range interval at constant VO(1), hour
IJK	Index for shifting SFC curves
XJ	Factor to convert SFC if SHP is less than 70% of design SHP
I	Working index for N
H	Head required, foot
SHPP	Total thrust required, horsepower
SHNG	Total thrust required per engine, horsepower
M	Working index for N
WT(ETIME)	Weight of fuel used in time increment ETIME, pound
DIS(ETIME)	Displacement at time increment ETIME, pound
VJJ(ETIME)	Jet velocity at time increment ETIME, foot per second

LIST OF VARIABLES USED IN PTTRN
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
PSI (N)	Current basepoint coordinate of parameter N
THETA (N)	Previous basepoint coordinate of parameter N
PHI (N)	Present exploratory point coordinate of parameter N
DEL (N)	Current step size of parameter N
DELMIN (N)	Minimum step size of parameter N
DIR (N)	Last successful direction of parameter N
SAVE (N)	Working variable for PHI (N)
S	Working variable for function value
SPHI	Working variable for function value at PHI coordinates
SPSI	Current best function value at PSI coordinates
NUMB	Counter for minimum step size check
RHO	Step size change factor
ICALL	Indicator of current point move
K	Index for do loop
I	Index for do loop
N	Number of parameters of search
SIGN (N)	Directed step size of parameter N

LIST OF VARIABLES USED IN OUTPUT
NOT IN COMMON

<u>Variable</u>	<u>Description</u>
IPRNT	Print data set reference number
J	Working variable for condition I
SUM	Total duct head loss, excluding elevation, foot
I	Index for do loop
DRATO	Strut diffuser area ratio
IK	Index for number of elbows in system
XNGT	Number of gas turbines
K	Index for do loop
L	Index for implied do loop in output statement
LL	Working variable to point to correct head loss for output
KLL	Working variable to point to correct format statement for head loss output
M	Index for implied do loop in output statement
NIMP	Number of impellers in pump
TFM	Strut thickness at flying waterline, foot
WTRAT	Total propulsion system weight ratio
WRATF	Propulsion system weight ratio, excluding fuel
ENGN(IENG)	Contains name of engine IENG
VJRAT(I)	Jet velocity ratio at craft condition I
VIRAT(I)	Inlet velocity ratio at craft condition I
HEADL(I,ICOMP)	Head loss of component ICOMP at craft con- dition I
CONDS(2,I)	Label for craft condition I

<u>Variable</u>	<u>Description</u>
ELBWS(2,IK)	Label for elbow IK
PC(I)	Propulsive coefficient at craft condition I
LABEL(5,M)	Labels for output



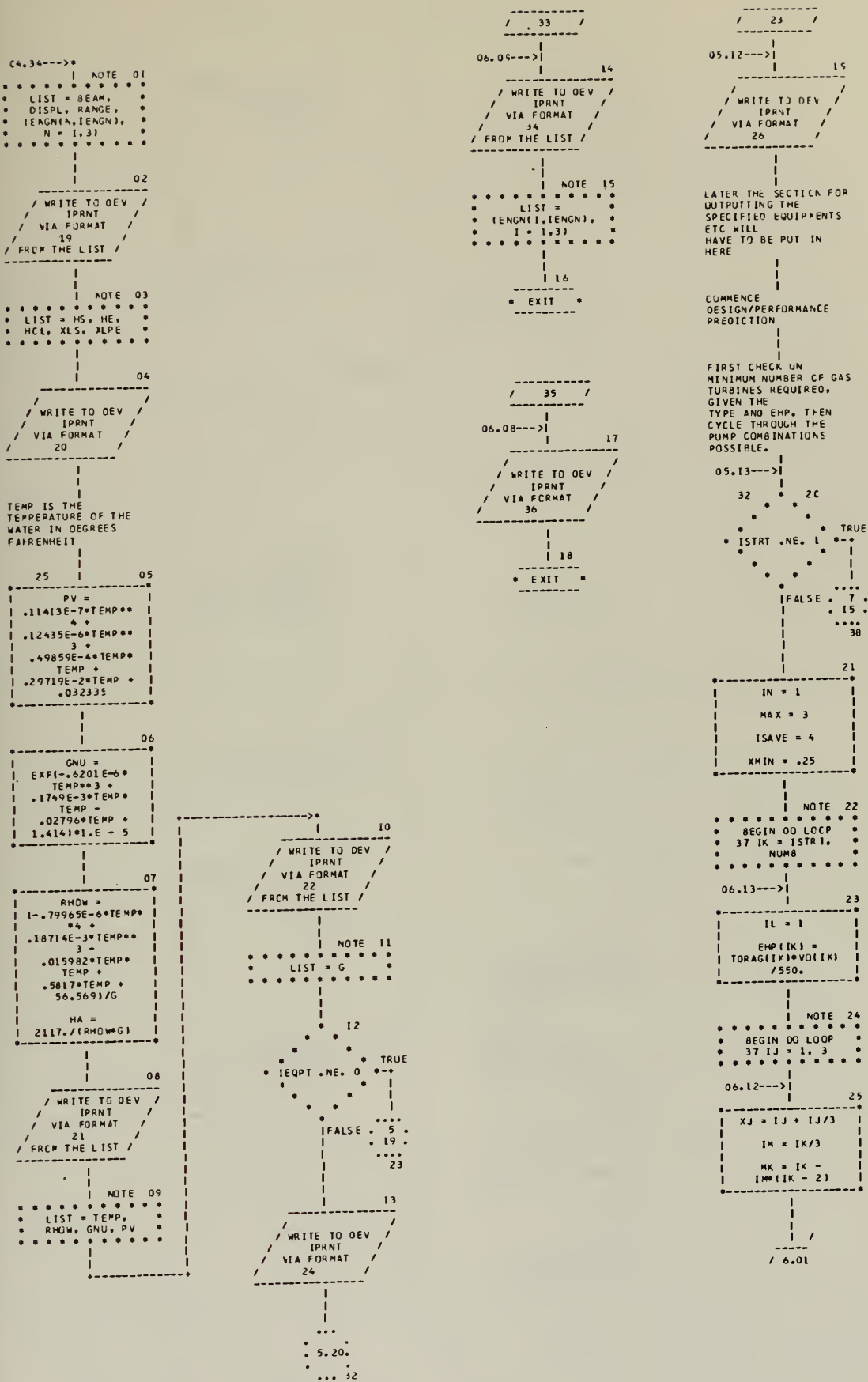


FIGURE 19 SUBROUTINE H2OJT FLOW DIAGRAM (CONT.)

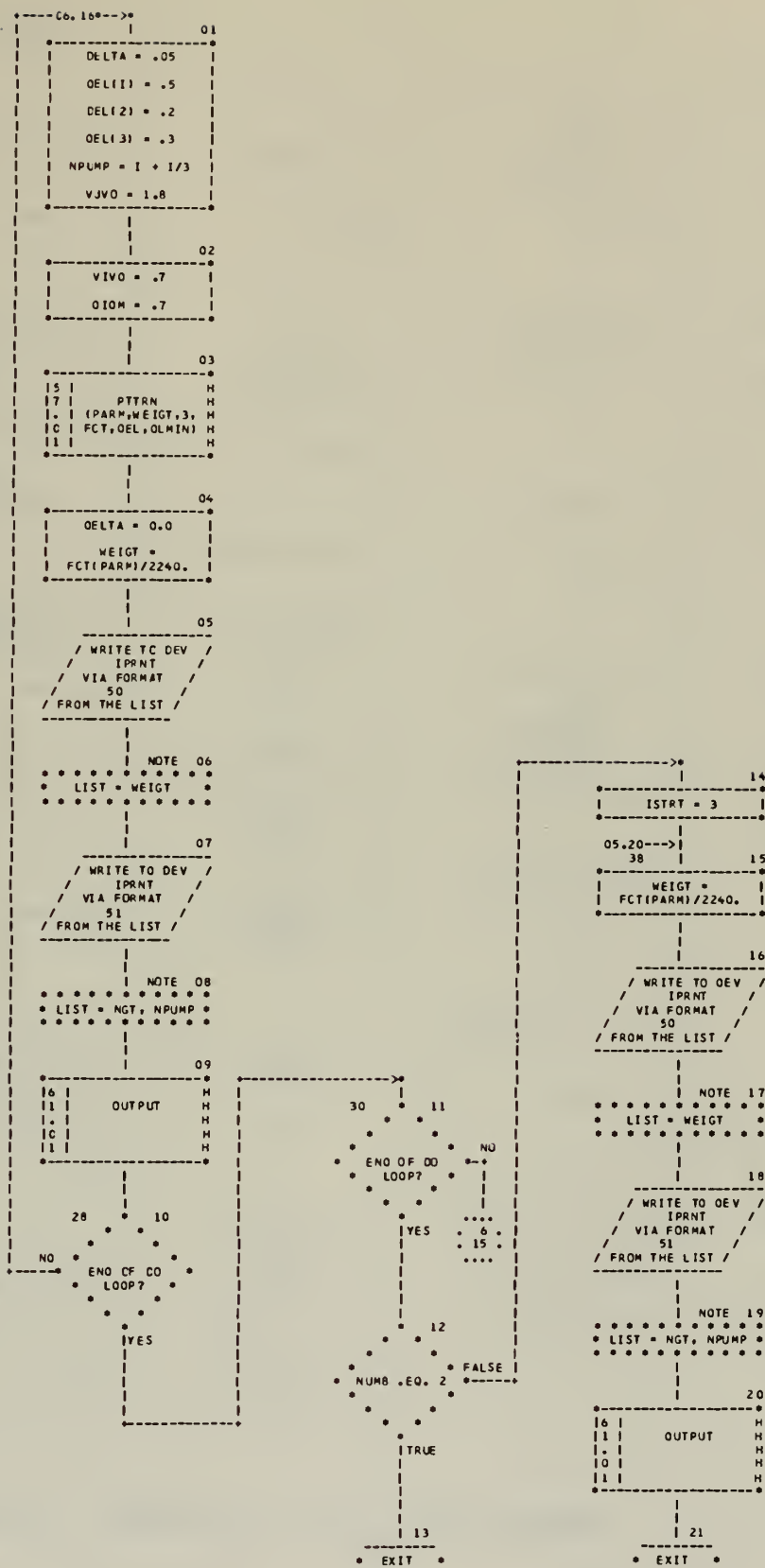
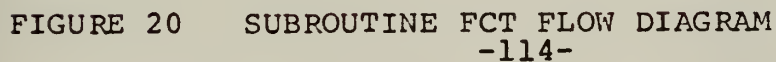


FIGURE 19 SUBROUTINE H2OJT FLOW DIAGRAM (CONT.)



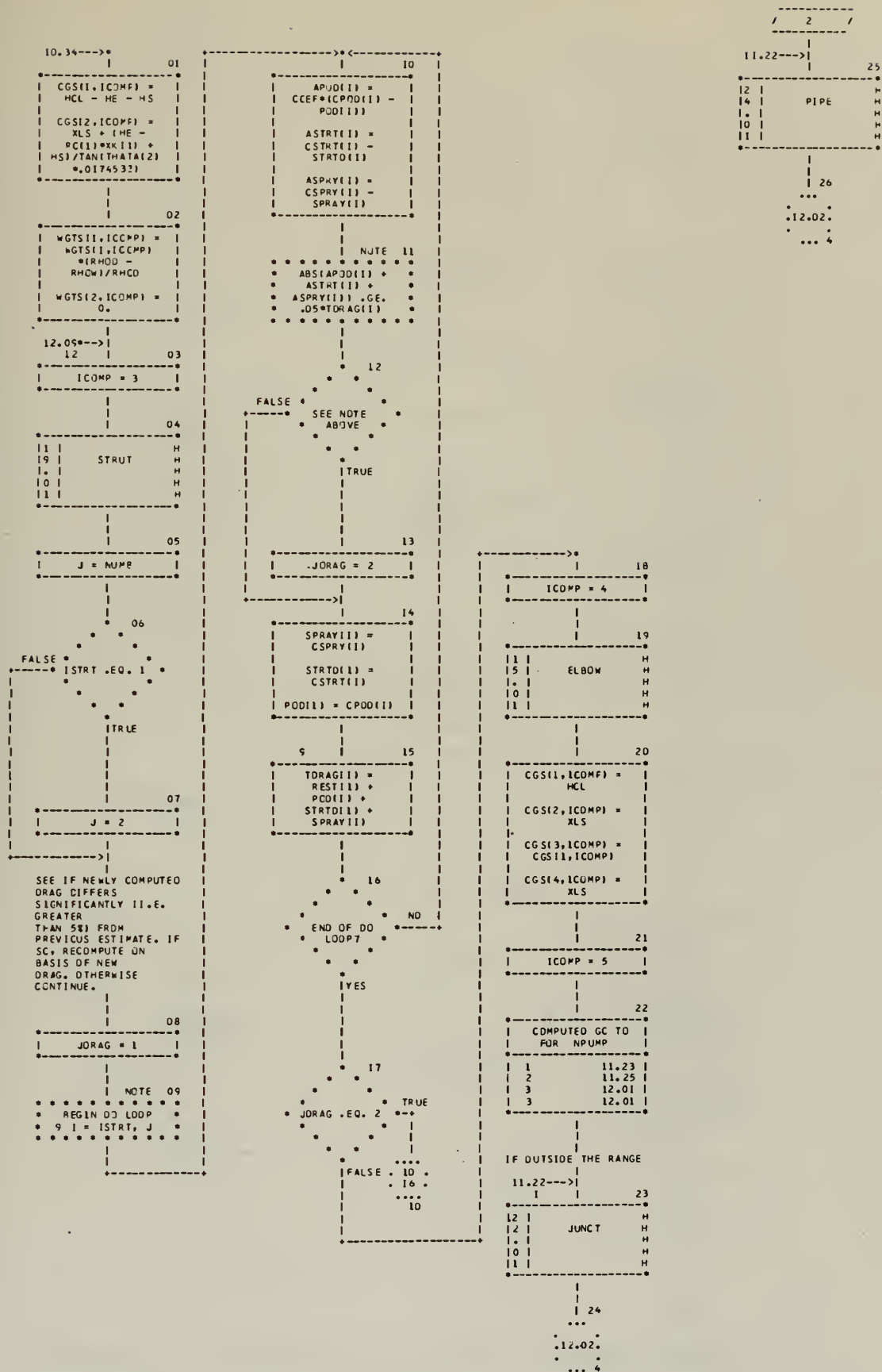


FIGURE 20 SUBROUTINE FCT FLOW DIAGRAM (CONT.)

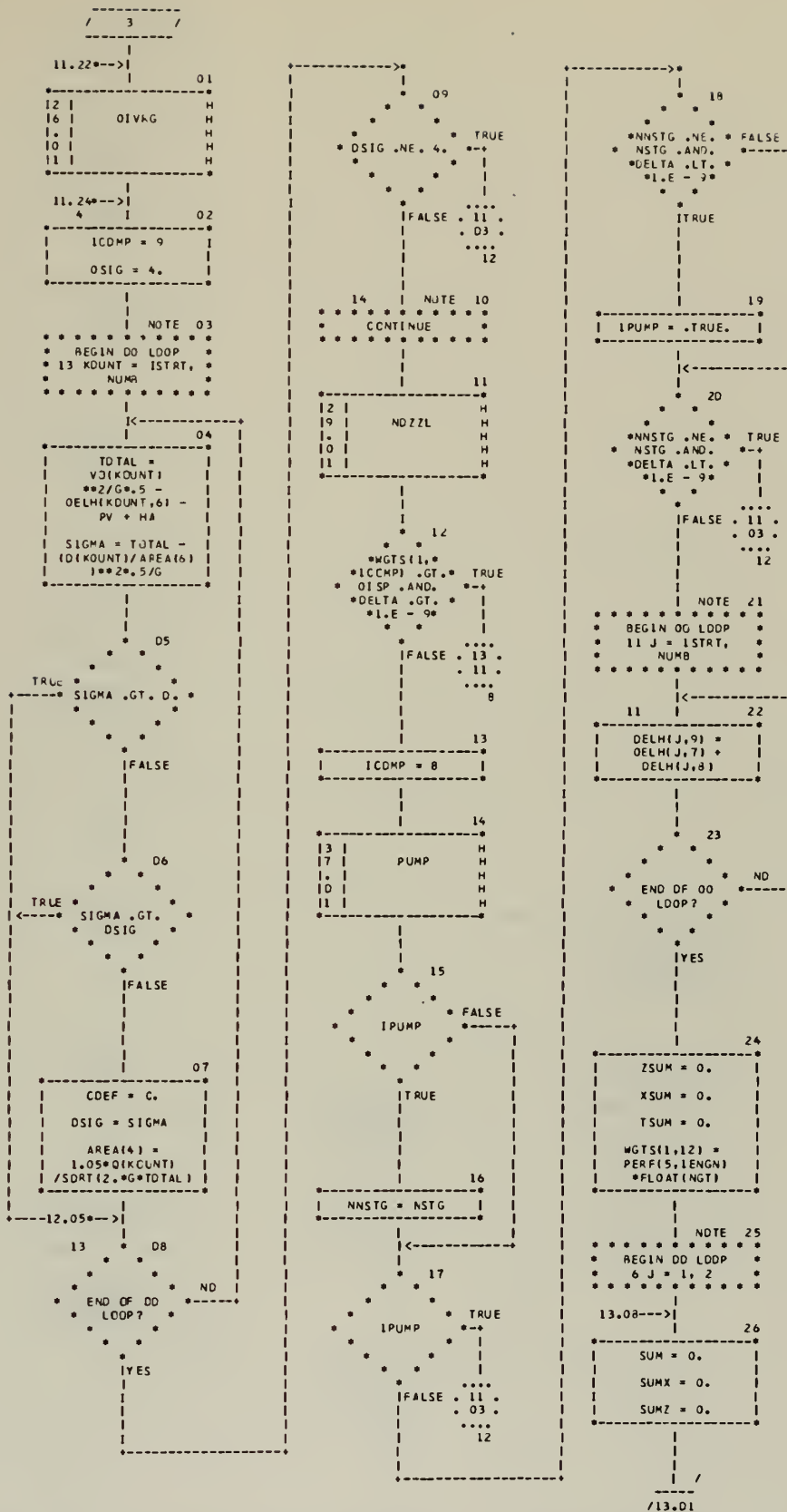


FIGURE 20 SUBROUTINE FCT FLOW DIAGRAM (CONT.)

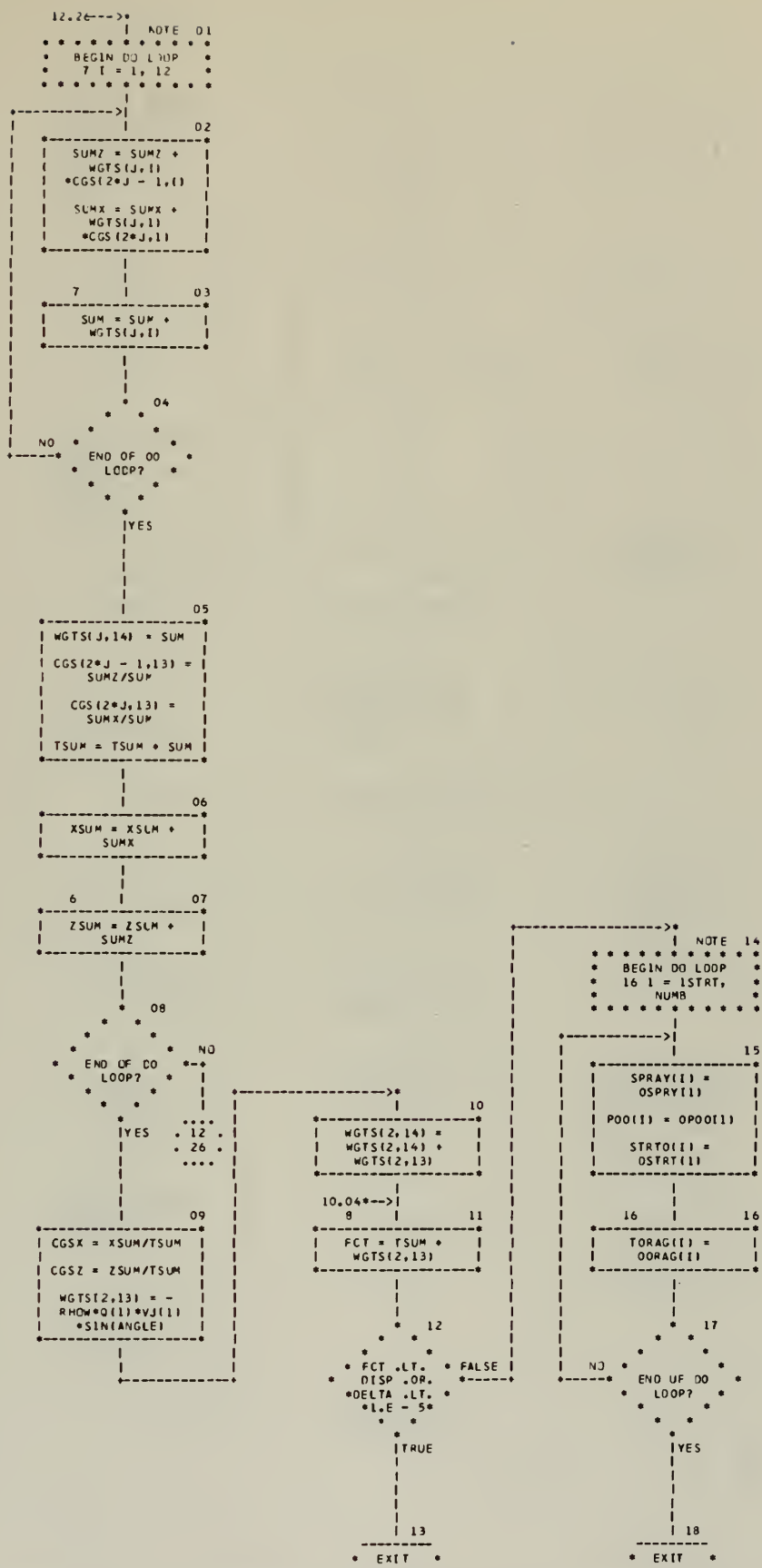


FIGURE 20 SUBROUTINE FCT FLOW DIAGRAM (CONT.)
-117-

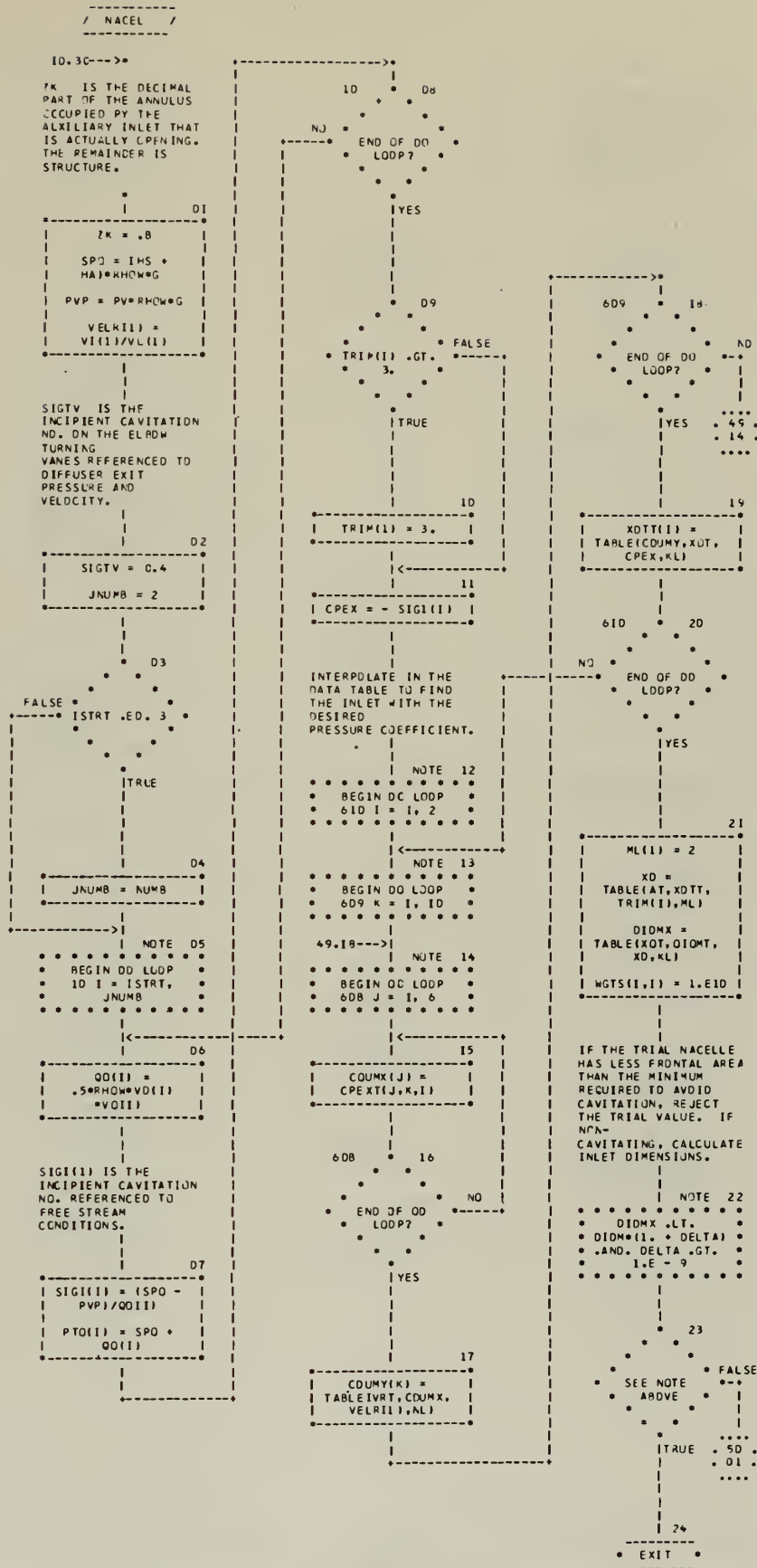


FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM
118-

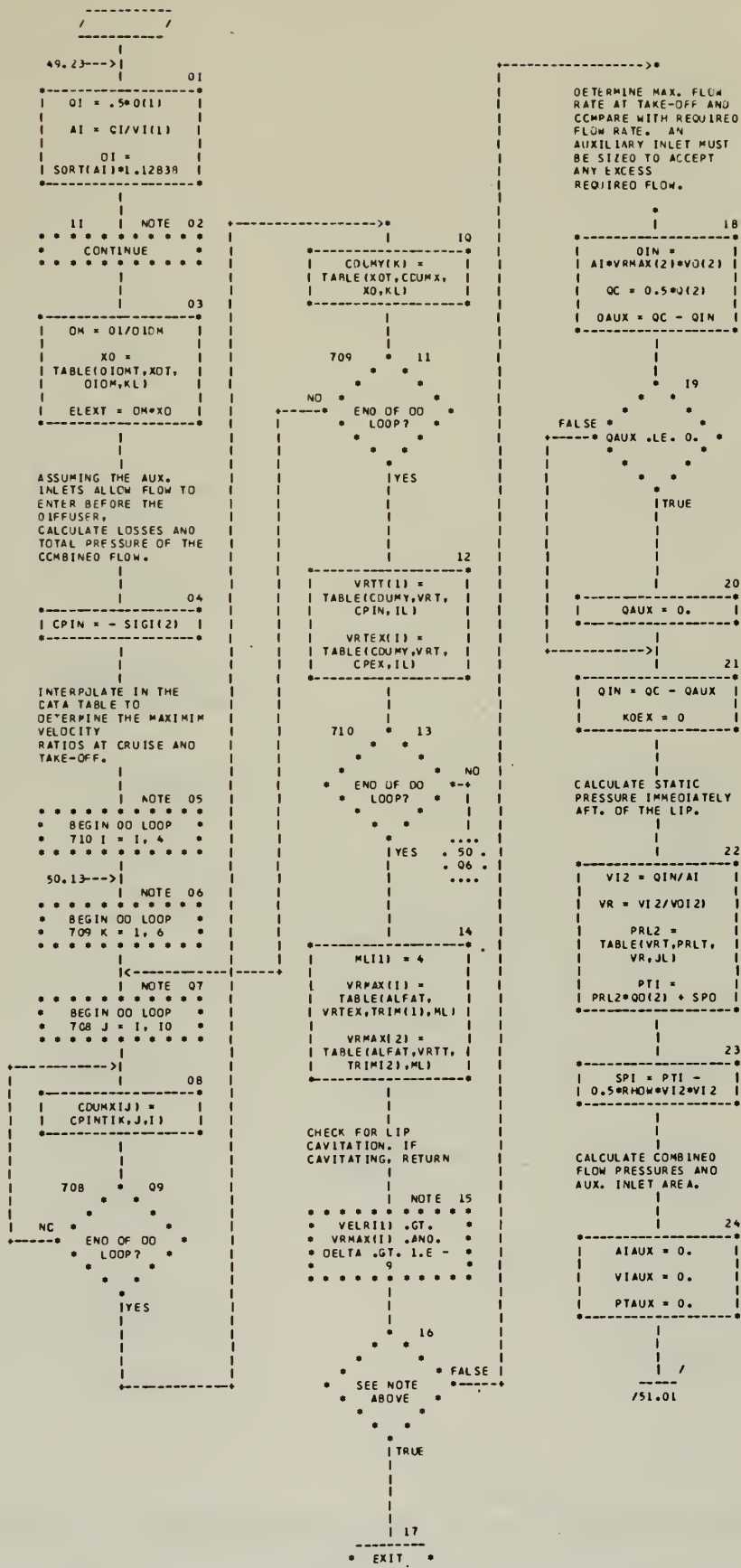


FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM (CONT.)

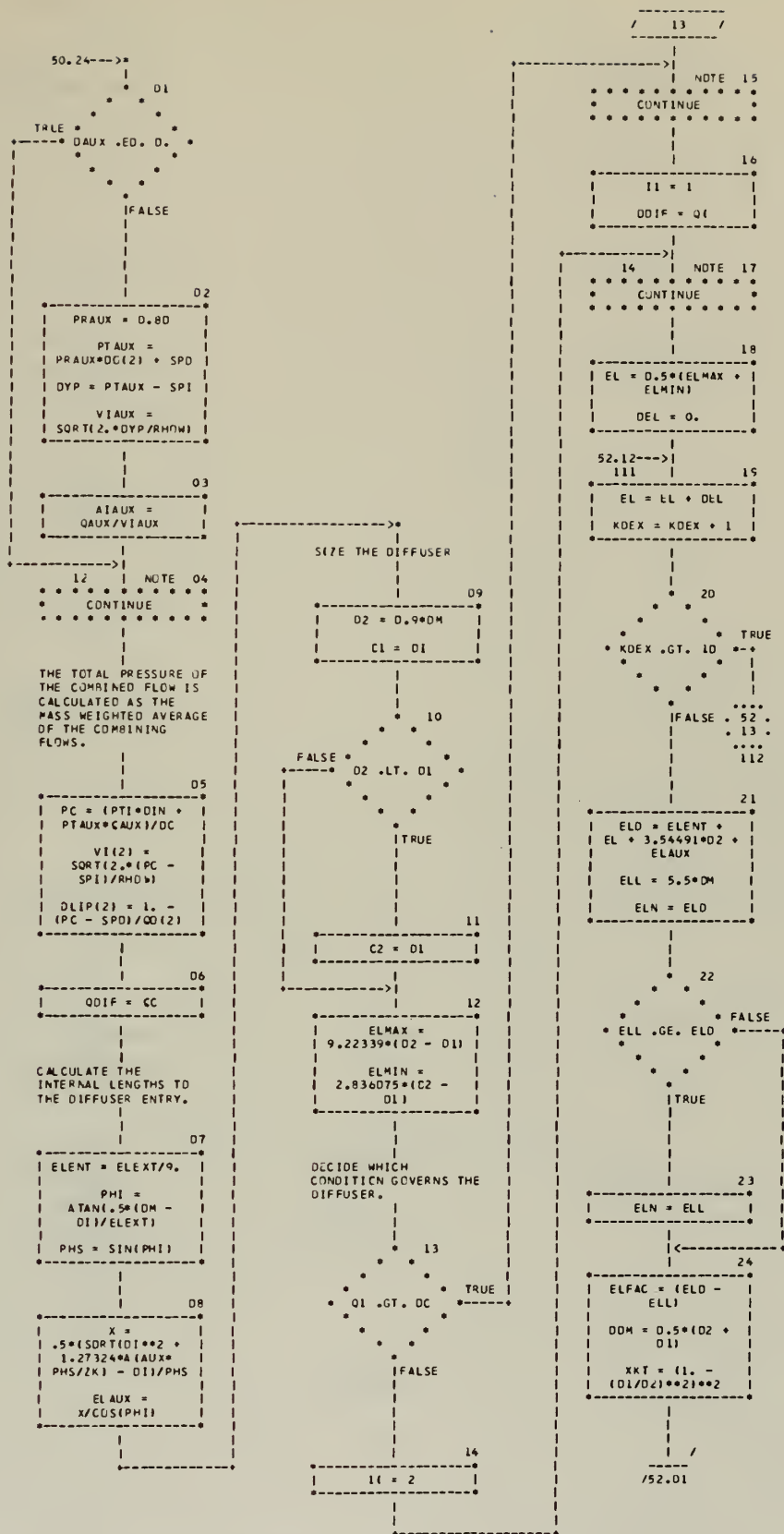


FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM (CONT.)

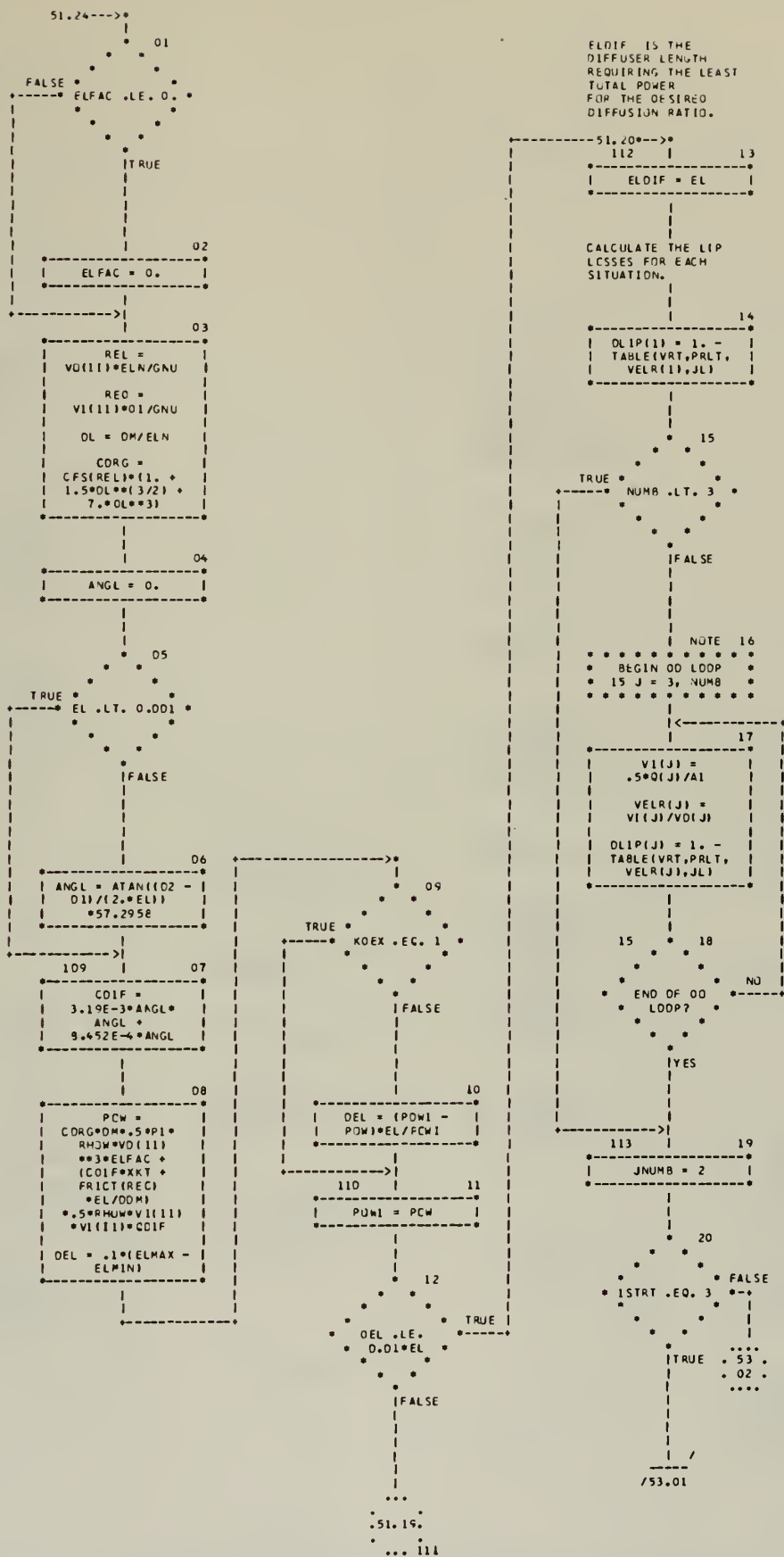
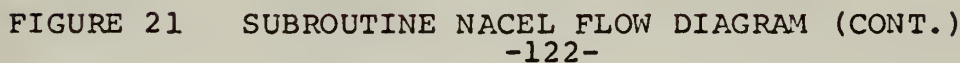


FIGURE 21 SUBROUTINE NACEL FLOW DIAGRAM (CONT.)



ELBOW

IC. 33-->

ELBOW PERFORMANCE AND DESIGN

REQUIRED INPUT
 WIDTH - WIDTH OF DUCT AT ELBOW INLET
 CEPTH - HEIGHT OF DUCT AT ELBOW INLET
 XK - RADIUS RATIO, RATIO OF THE RADIUS OF THE CENTERLINE OF BEND TO THE INTERNAL RADIUS OF THE DUCT
 Q - FLOW RATE, IN CUBIC FEET PER SECOND
 AREA - CROSS SECTIONAL AREA OF DUCT AT THE ELBOW, PRESUMED SAME AT THE INLET AND THE OUTLET
 THETA - ANGLE OF BEND, FROM HORIZONTAL TO OUTSIDE EDGE
 GNMU - VISCOSITY OF STANDARD (35 PER CENT SALINITY) SALT WATER
 PI - 3.14159265
 ICCMP - INDEX INDICATING WHICH COMPONENT IS BEING LOCKED AT
 ISTRT - INDEX NOTING WHICH MODE OF OPERATION FOR THE HYDROFOIL
 NLMB - INDEX NOTING HOW MANY MODES TO BE CONSIDERED DURING THIS PASS

01
 REMAX = 4.E+5
 KOUNT = ISTRT
 IELB = ICCMP - ICCMP/2
 AREA(ICMP) = AREA(ICMP - 1)

02
 AREA1 = .5*AREA(ICMP)

03
 FALSE
 IELB .EQ. 4
 TRUE

04
 AREA1 = .5*AREA1

05
 DETERMINE SHAPE
 IJ = 0
 IK = 1

06
 FALSE
 WIDTH .EQ. DEPTH
 TRUE
 07
 IJ = 1
 08
 NOTE
 ABS(WIDTH-DEPTH) - AREA1 .LT. .05*AREA1

09
 FALSE
 SEE NOTE ABOVE
 TRUE
 10
 IK = 3
 11
 ITYPE = IJ + IK

ITYPE SHAPE
 1 ELLIPSE
 2 CIRCLE
 3 RECTANGLE
 4 SQUARE

12
 FACTR = (1.00229 + .041452*XK(IELB) **(-1.96))
 *XK(IELB)**.84

DETERMINE EQUIVALENT RADII

13
 RD(IELB) = .5*DEPTH

14
 FALSE
 ITYPE .EQ. 1
 TRUE
 15
 RD(IELB) = .5*(DEPTH*SQRT(2/(WIDTH**2 + DEPTH**2)))

TRANSFER SHAPE TO CALLING PROGRAM

NOTE 16
 BEGIN DO LOOP
 N = 1, 3

17
 TYPE(N,IELB) = SHAPE(N,ITYPE)

18
 NO
 END OF DO LOOP?

YES

FIND BEND RADII

19
 RIN = RD(IELB)
 *XK(IELB) - 1.
 ROUT = RIN + 2*RD(IELB)

IF XK=R/RC IS LE. 1. DO NOT USE SPLITTERS METHOD... USE THIN TURNING VANES CALCULATION

20
 TRUE
 XK(IELB) .LE. 1.
 FALSE
 17
 01
 100

DETERMINE NUMBER OF VANES REQUIRED FOR MINIMUM LOSS

RATIO IS THE OPTIMUM RATIO OF THE INPCAD AND OUTBOARD RADII FOR MINIMUM LOSS IN THE BEND

22
 RATIO = 4.3
 XN = ALG((XK(IELB) - 1.)/(XK(IELB) + 1.))
 /ALG((RATIO - 1.)/(RATIO + 1.))
 N = XN + .5

23
 FALSE
 N .EQ. 0
 TRUE
 24
 N = 1
 25
 N1 = N - 1

26
 FALSE
 N1 .LE. 0
 TRUE
 27
 N1 = 1

FIND THE RATIO OF THE INSIDE RADIUS TO OUTSIDE RADIUS OF ANY OF THE SUBDIVIDED ELBOWS

28
 RATED = (RIN/ROUT) ** (1./FLOAT(N))

N = NUMBER OF SUBDIVIDED ELBOWS
 N1 = NUMBER OF SPLITTERS

COMPUTE HEAD LOSSES FOR EACH SUBDIVIDED ELBOW, STARTING FROM INSIDE

16.29

FIGURE 22 SUBROUTINE ELBOW FLOW DIAGRAM

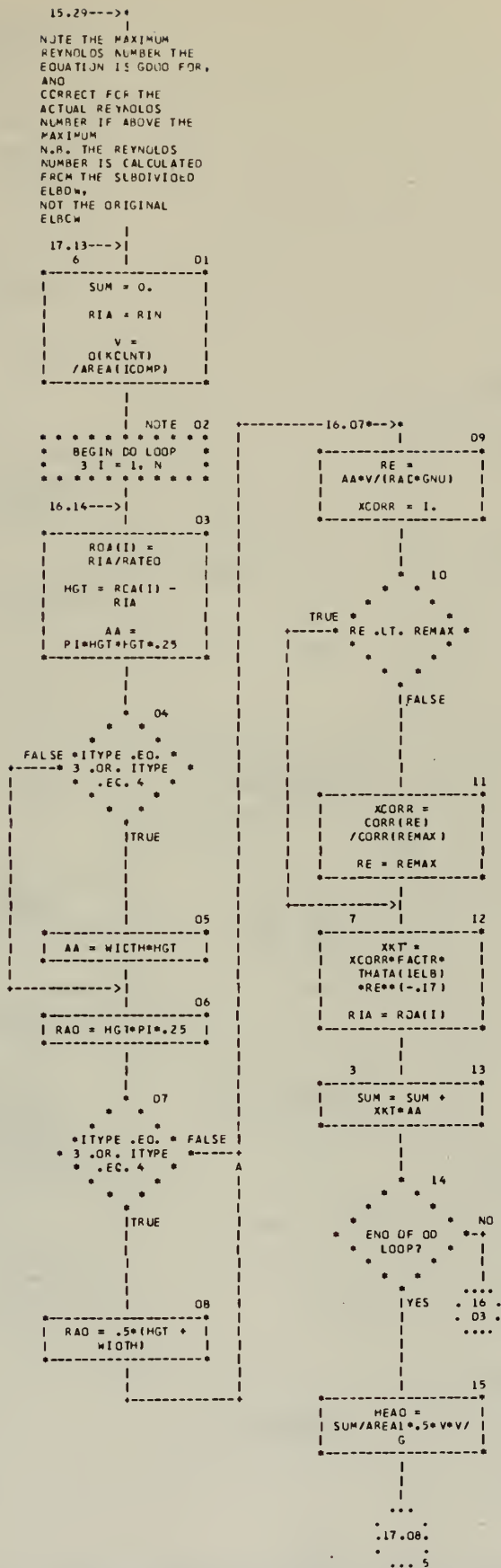


FIGURE 22 SUBROUTINE ELBOW FLOW DIAGRAM (CONT.)
-124-

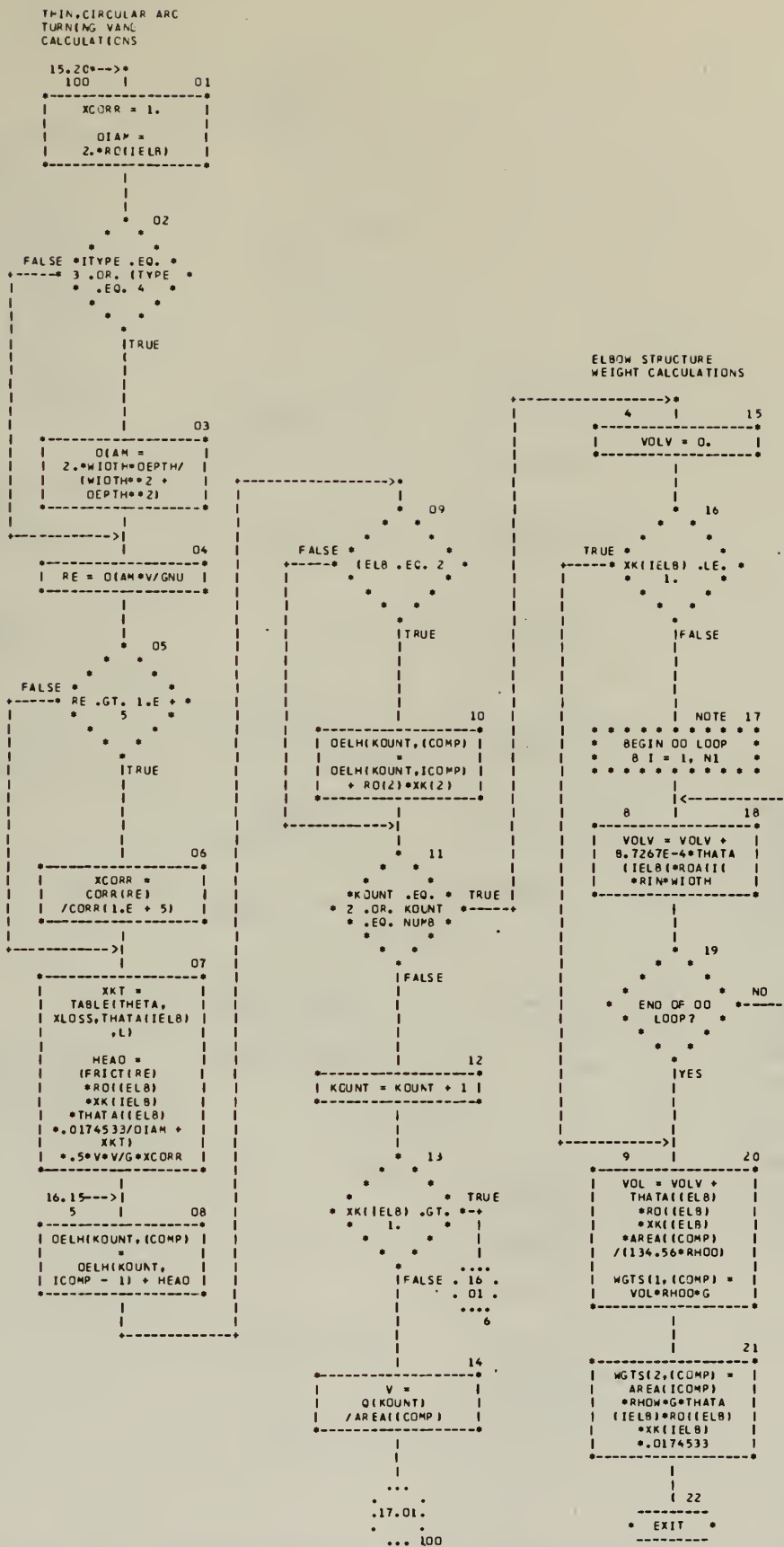


FIGURE 22 SUBROUTINE ELBOW FLOW DIAGRAM (CONT.)

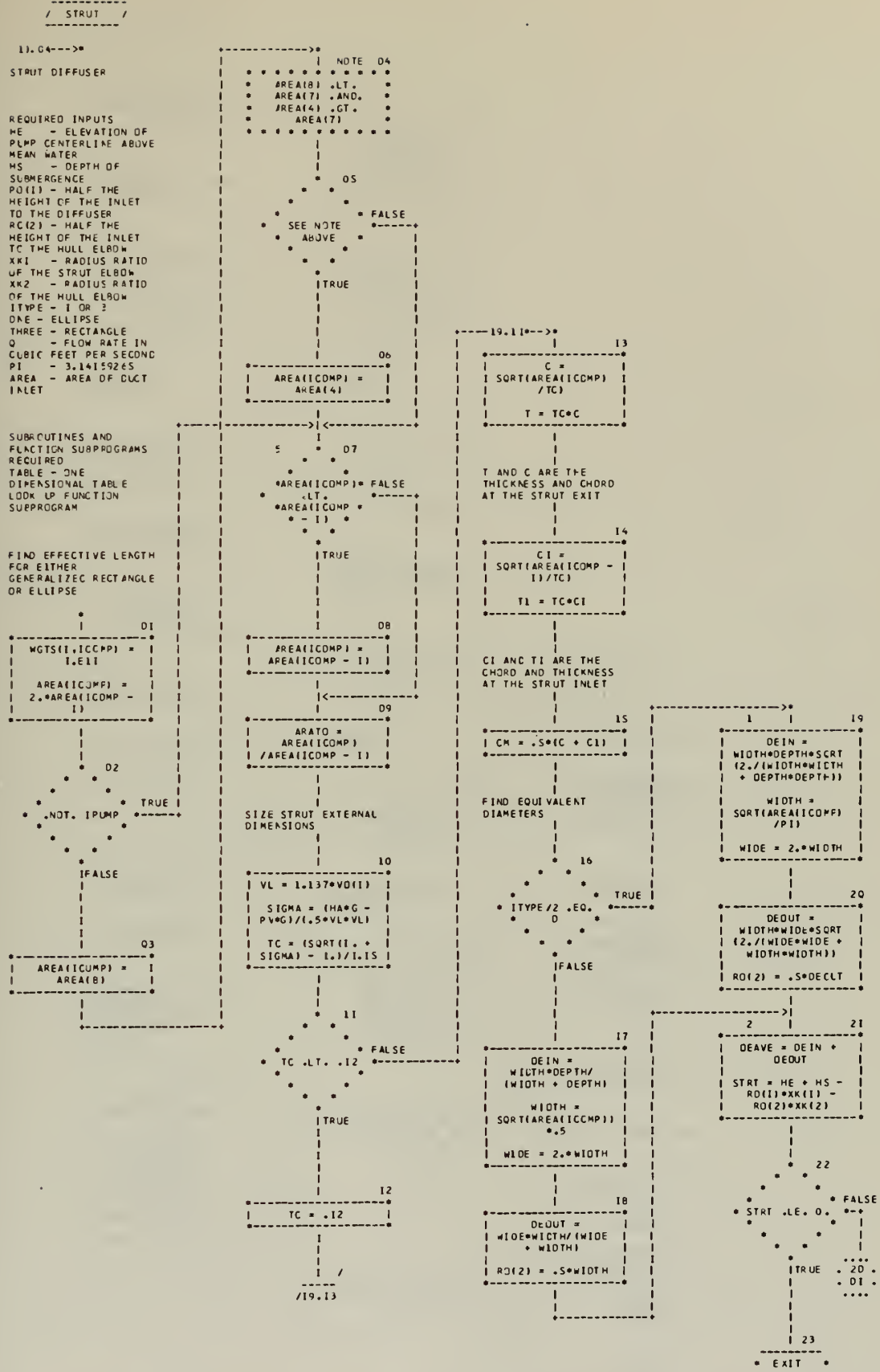


FIGURE 23 SUBROUTINE STRUT FLOW DIAGRAM
-126-

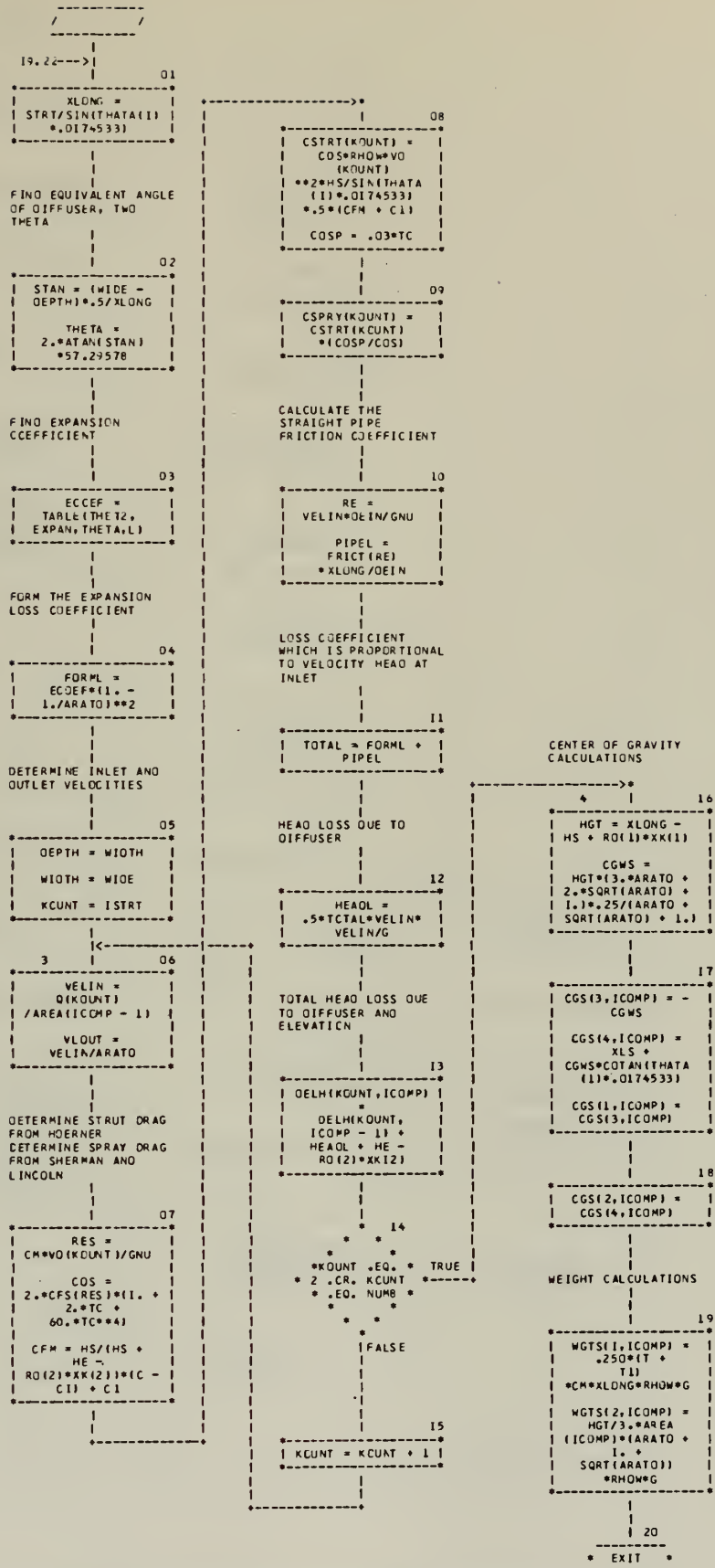


FIGURE 23 SUBROUTINE STRUT FLOW DIAGRAM (CONT.)
-127-

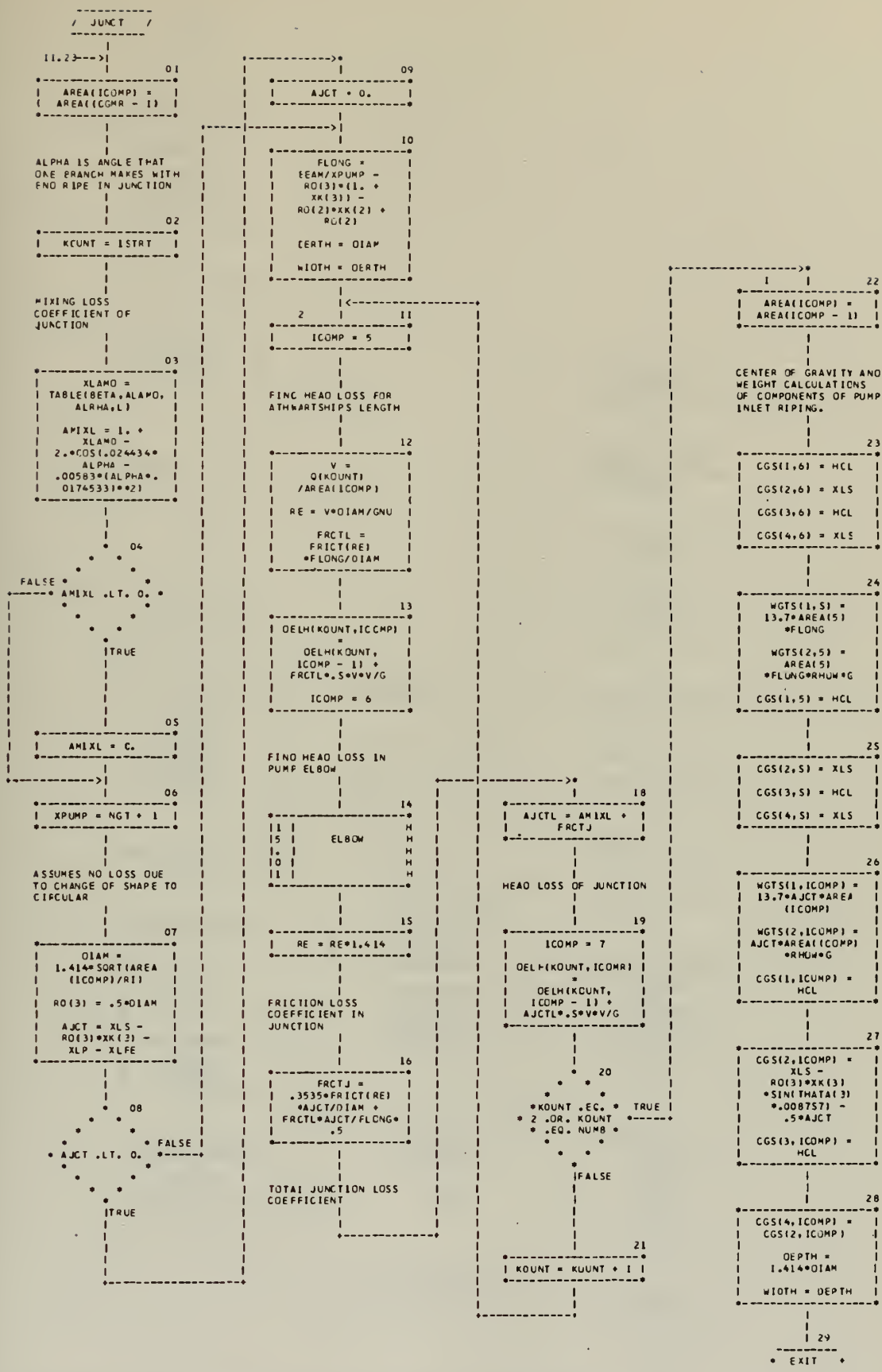


FIGURE 24 SUBROUTINE JUNCT FLOW DIAGRAM
-128-

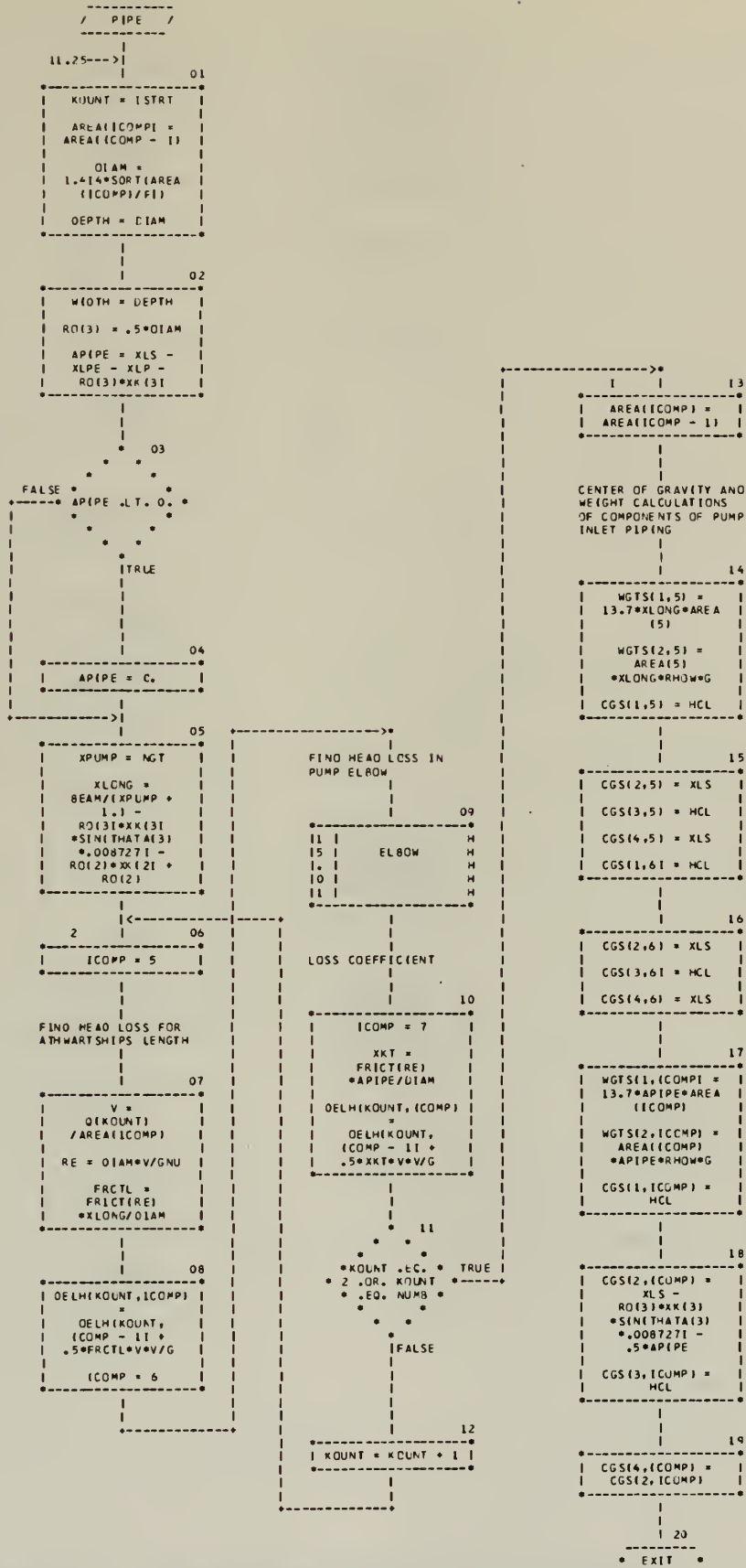
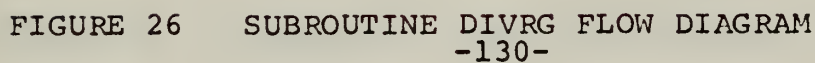


FIGURE 25 SUBROUTINE PIPE FLOW DIAGRAM



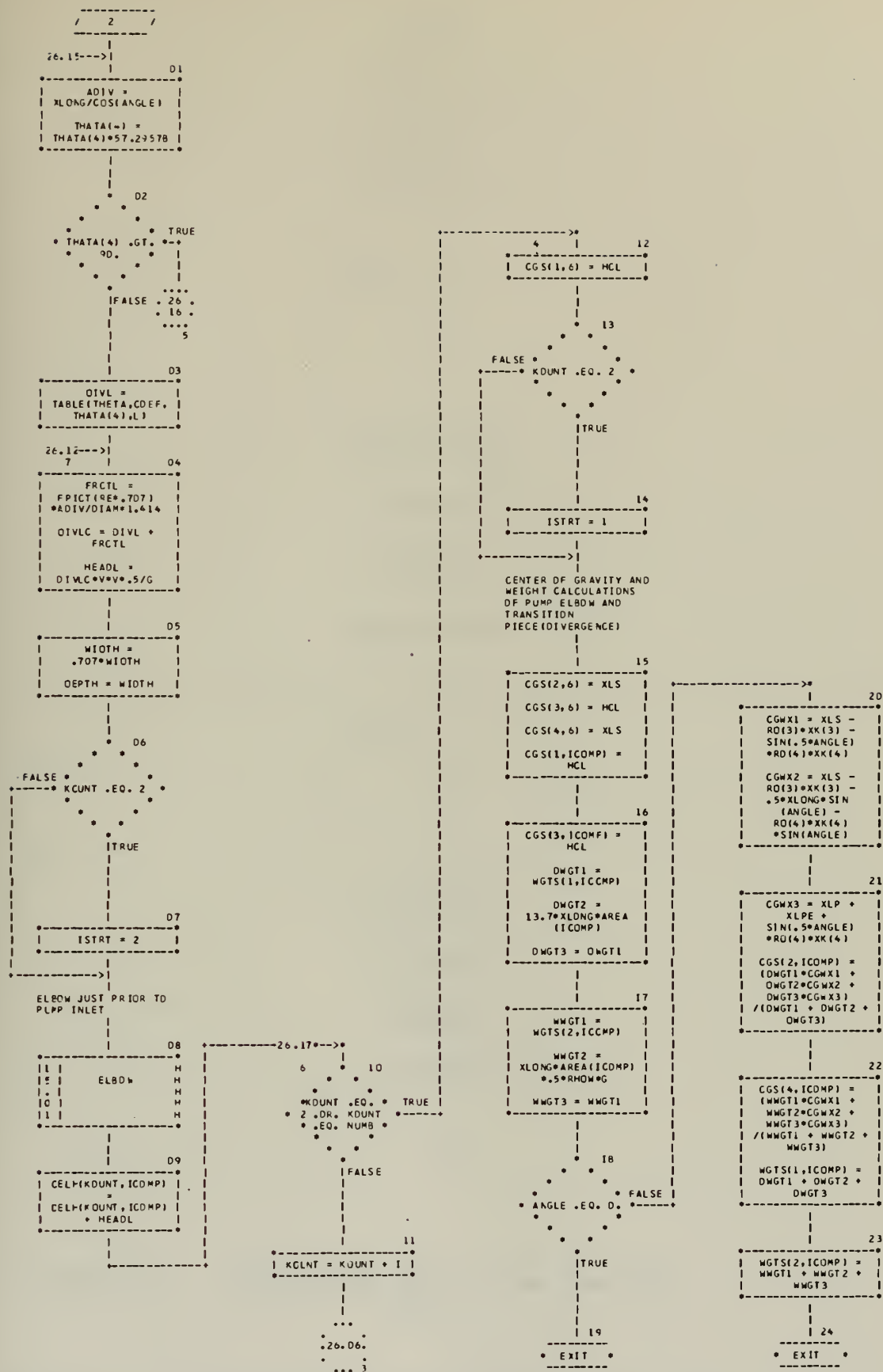


FIGURE 26 SUBROUTINE DIVRG FLOW DIAGRAM (CONT.)

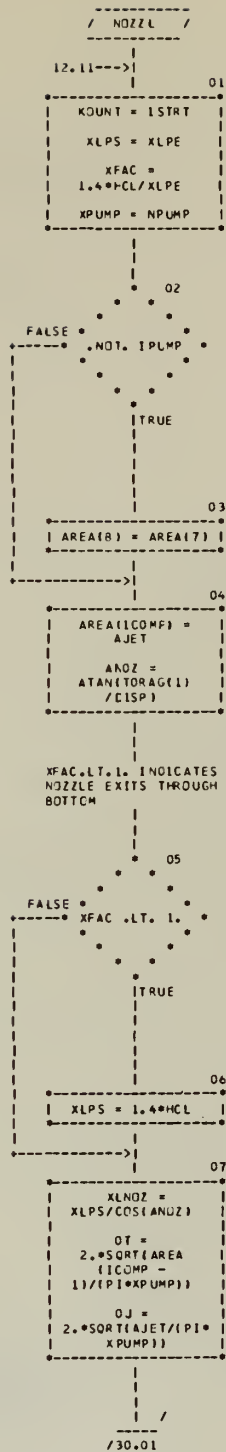


FIGURE 27 SUBROUTINE NOZZL FLOW DIAGRAM
-132-

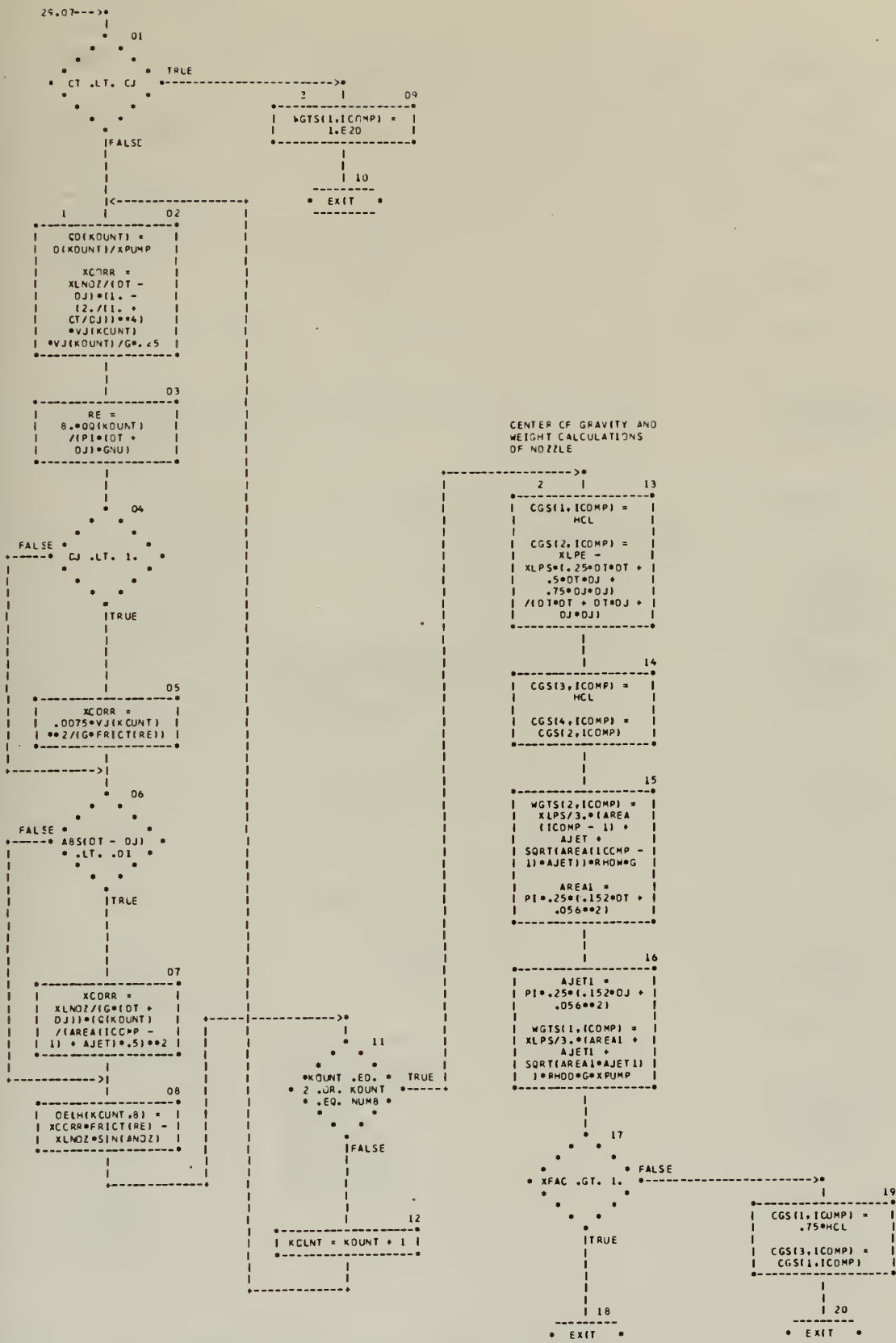


FIGURE 27 SUBROUTINE NOZZL FLOW DIAGRAM (CONT.)

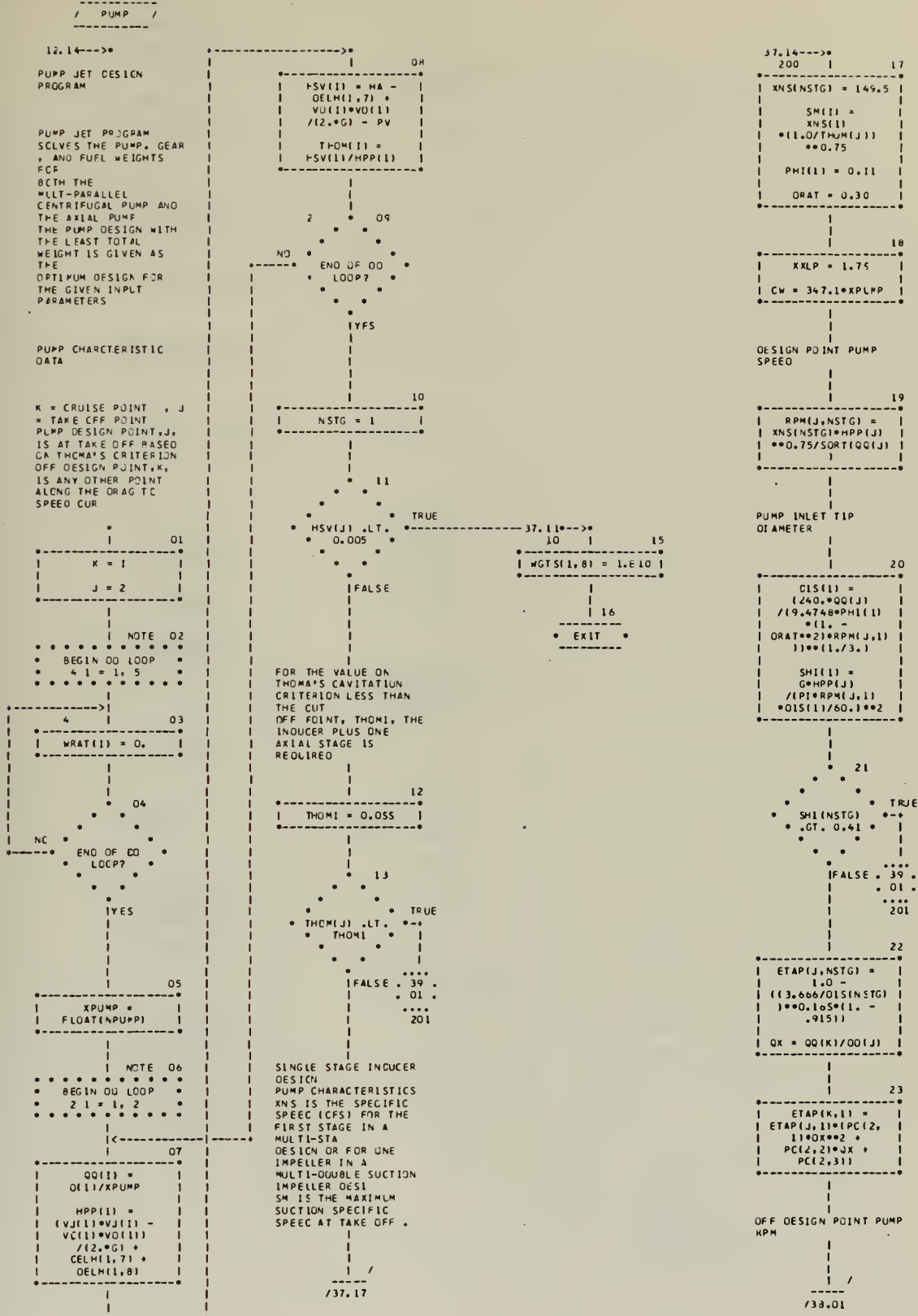


FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM
-134-

INDUCER PLUS ONE
AXIAL STAGE DESIGN

37.13-->*
201 1 01
THCMI = 0.058
NSTG = 2
HP = HSV(J)/THCMI

THOMS IS THOMA'S
CAVITATION CRITERION
FOR THE AXIAL STAGE
BASED ON A MAXIMUM S
OF 10,000 AND NS=3619

02
THOMS = 0.258

INDUCER SPECIFIC
SPEED AND FLOW COEFF.

03
XNSINSTG = 149.5
PHI(2) = 0.15
CRAT = 0.3
XXLP = 1.71
CW = 393.5*XPUMP

DESIGN PUMP SPEED

04
RPM(J,NSTG) =
XNSINSTG
*HP**0.75/SDRT
(DD(J))

PUMP INLET TIP
DIAMETER

05
DIS(2) =
(240.*DD(J))
/(9.4748*PHI(2)
*(1. -
CRAT**2)*RPM(J,2)
)**(1./3.)
ETAP(J,NSTG) =
1.0 -
((3.666/DISINSTG)
)**0.165*(1. -
.915)

06
OX = DD(K)/CO(J)
ETAP(K,NSTG) =
ETAP(J,NSTG)
*(PCA(2,1)
*OX**2 +
PCA(2,2)*CX +
PCA(2,3))

OFF DESIGN POINT RPM

08
CA =
PCA(1,2)/PCA(1,3)
*0.5
CB =
PCA(1,1)/PCA(1,3)
*HX =
HPP(K)/HPP(J)

09
RX = -CA*CX +
SDRT(OX*DX*(CA*
CA - CB) +
HX/PCA(1,3))
*(CA/ABS(CA))
RPM(K,NSTG) =
RPM(J,NSTG)*RX

10
PHRAT = OX/RX
SMINSTG) =
XNSINSTG
*(HP/HSV(J))
*0.75

11
* (HSV(J) * TRUE
* HP)/(HPP(J) *
* HP) .LT.
* THOMS
*
FALSE

12
SMI(2) =
G*HP/(PI*RPM(J,2)
*DIS(2)/60.)*2

...
.38.04.
... 203

INDUCER PLUS TWO
AXIAL STAGES DESIGN

202 1 13
HMP = (HPP(J) -
HP)/2.0
NSTG = 3
XXLP = 2.03
CW = 439.5*XPUMP
XNS(3) = XNS(2)

14
SMI(3) = SMI(2)
DIS(3) = DIS(2)
SMI(3) = SMI(2)
PHI(3) = PHI(2)

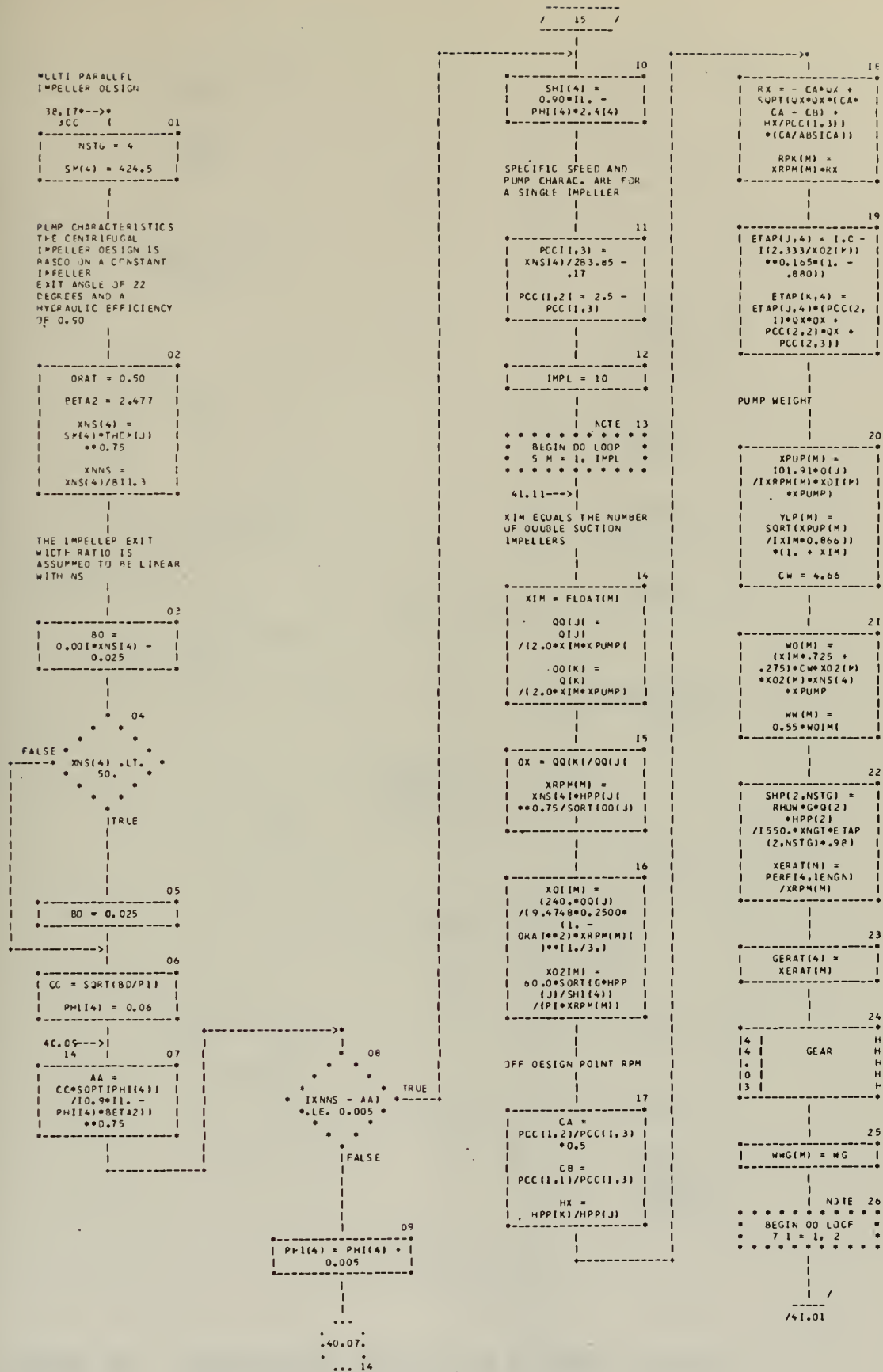
15
RPM(J,3) =
RPM(J,2)
RPM(K,3) =
RPM(K,2)
ETAP(J,3) =
ETAP(J,2)
ETAP(K,3) =
ETAP(K,2)

16
* (HSV(J) * TRUE
* HP)/(HMP) .LT.
* THOMS
*
FALSE

37.
.15.
...
10

...
.38.04.
... 203

FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM (CONT.)
-136-



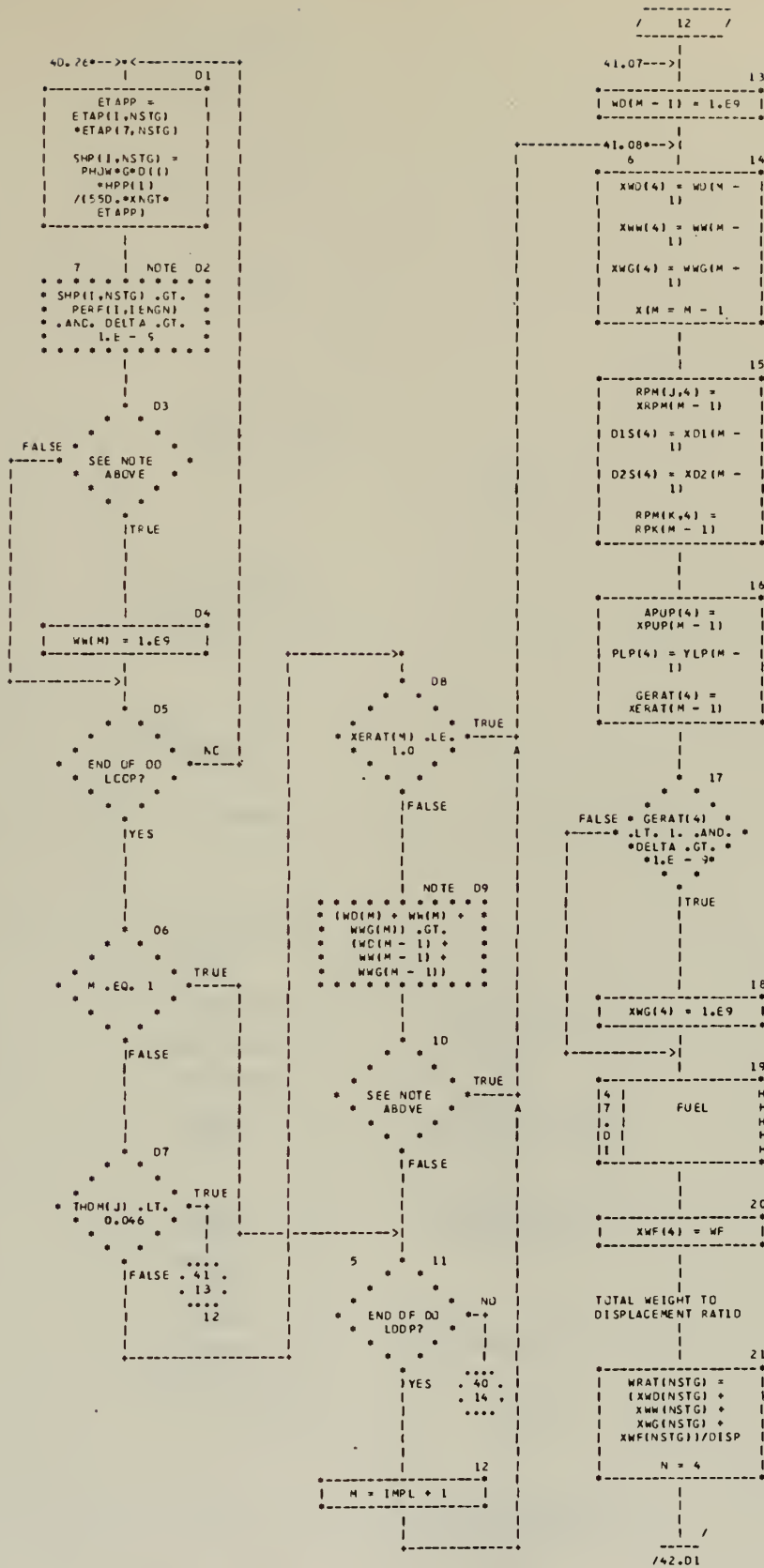


FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM (CONT.)

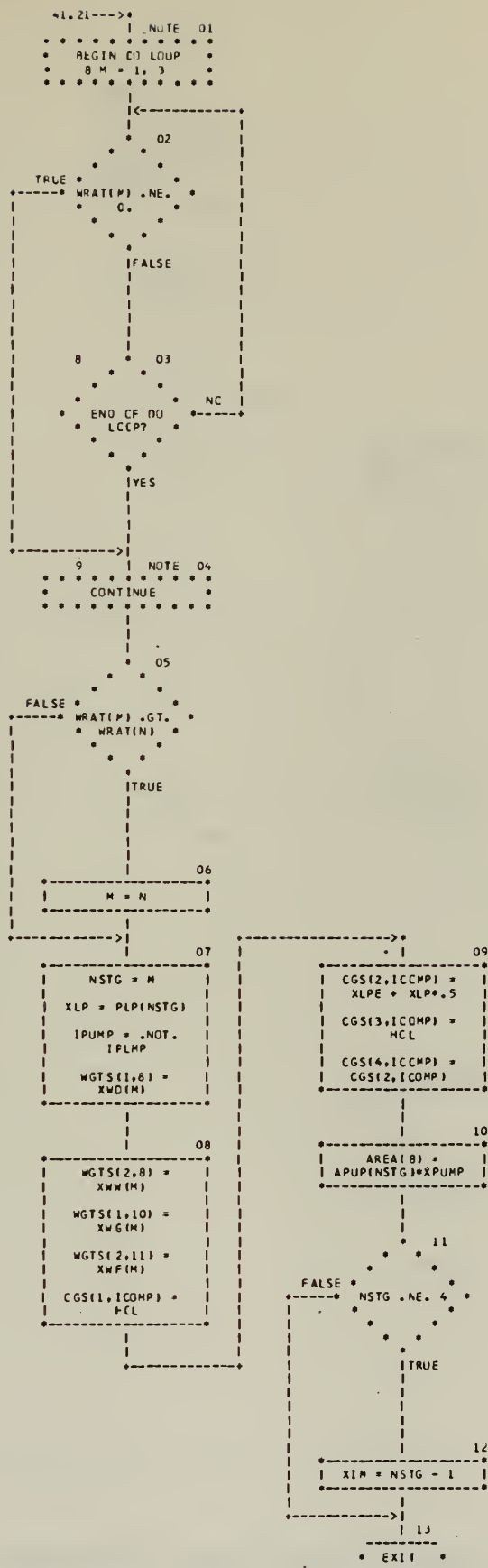


FIGURE 28 SUBROUTINE PUMP FLOW DIAGRAM (CONT.)

GEAR

38.C90-->=

GEAR PUMP
ARRANGEMENT. IF NO.
OF PUMPS = 5 NO. OF
GTS, A PLANETARY
WILL BE USED. IF TWO
PUMPS PER GT OR TWO
GTS PER PUMP A
COMBININ
REDUCTION GEAR WITH
TOLER WILL BE USED.

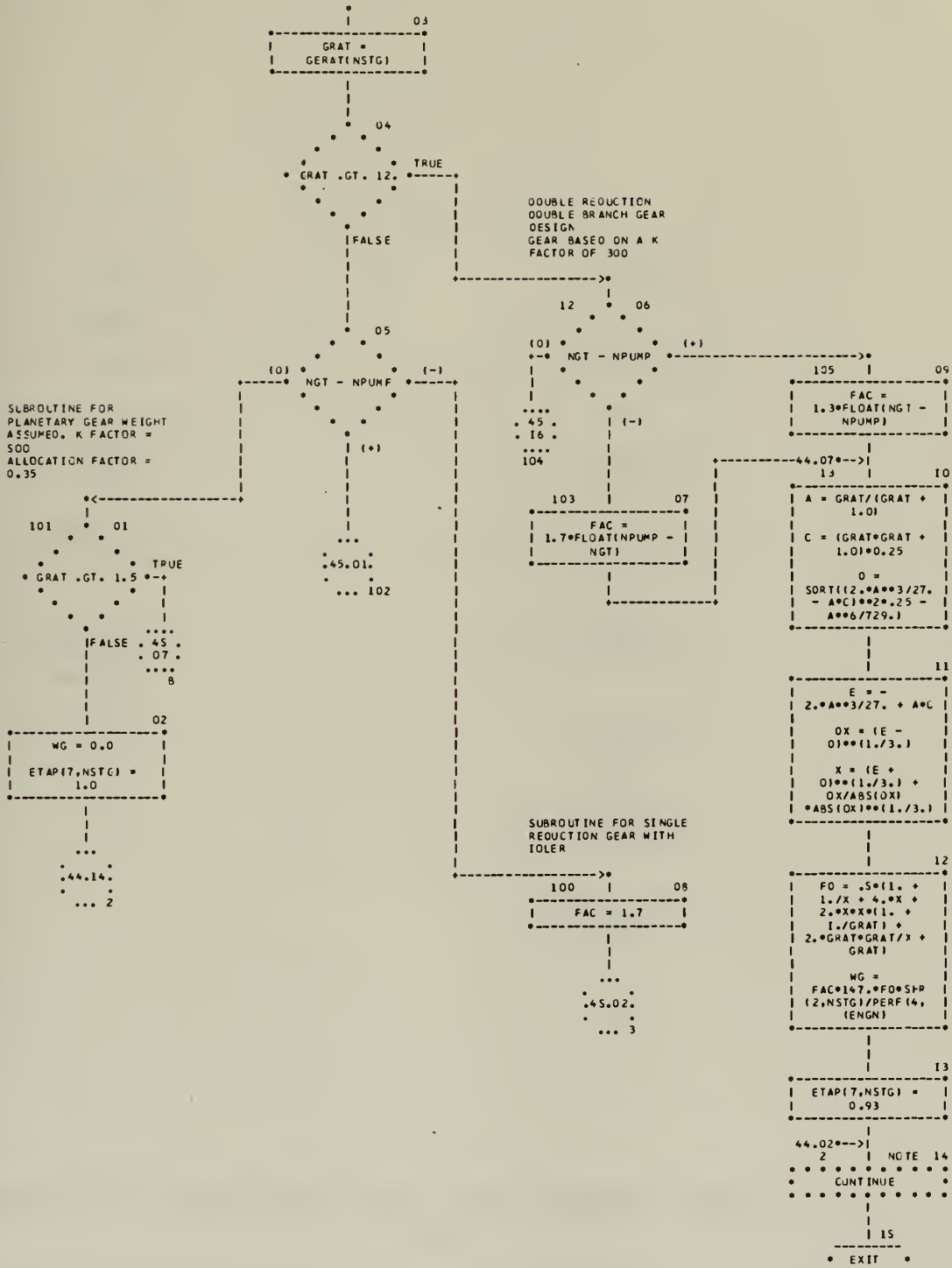


FIGURE 29 SUBROUTINE GEAR FLOW DIAGRAM
-140-

/ FUEL /

30.18-->

FUEL WEIGHT AT
CONSTANT SPEED
ASSUMING SFC =
CSF*SHP TC 1/4 AND E

FUEL CALCULATIONS
BASED ON CONSTANT
SPEED THROUGHOUT
RANGE. DURATI
TRAVEL DIVIDED INTO
20 SEGMENTS AND FUEL
WEIGHT CALCULATED UN
REVI
SHP REQUIREMENTS DUE
TO WEIGHT DECREASE

D1
CFS =
PERF(3, LENG)
* PERF(1, LENG)
* 0.25
CA =
TORAG(1)/DISP

D2
CD = 1.0 +
(DELH(1,8) +
DELH(1,7))
* 2.0 * G / (VJ(1)
* VJ(1))
WT(1) = 0.0
DIS(1) = DISP
N = 21

D3
XN = 20.
TI =
RANGE / (VC(1) * XN)
* 1.689
IJK = 0
XJ = 0.75

NOTE 04
BEGIN DO LOOP
I I = 2, N

D5
DIS(I) = DIS(I -
1) - WT(I - 1)
VJJ(I) =
VO(1) / 2.0 +
SQRT (VO(1)
* 2 / 4.0 +
DIS(I)
* CA / (RHO * AJET))

D6
H =
CO * VJJ(I) * VJJ(I)
/ (2. * G) -
VO(1) * VO(1)
/ (2. * G) + HE
SHP =
(RHO * G * AJET * VJJ
(I) * H)
/ (550. * ETAP(1,
NSTG) * ETAP(17,
NSTG))

C7
SHNG =
SHP / FLOAT(NGT)

NOTE 08
SHNG .GT.
D.7 * PERF(1, LENG)
.OR. (JK .EQ. 1

D9
TRUE
SEE NOTE
ABOVE
FALSE

10
CFS =
CFS * SQRT (SHNG)
IJK = 1
XJ = 0.25

11
WT(I) =
CFS * TI * SHPP * XJ *
FLCAT(NGT) * (1. -
XJ)

12
END OF DO
LOOP?
YES
NO

NOTE 13
BEGIN DO LOOP
2 M = 2, N

14
WT(M) = WT(M) +
WT(M - 1)

15
END OF DO
LOOP?
YES
NO

16
WF = WT(N)

17
EXIT

FIGURE 30 SUBROUTINE FUEL FLOW DIAGRAM
-142-

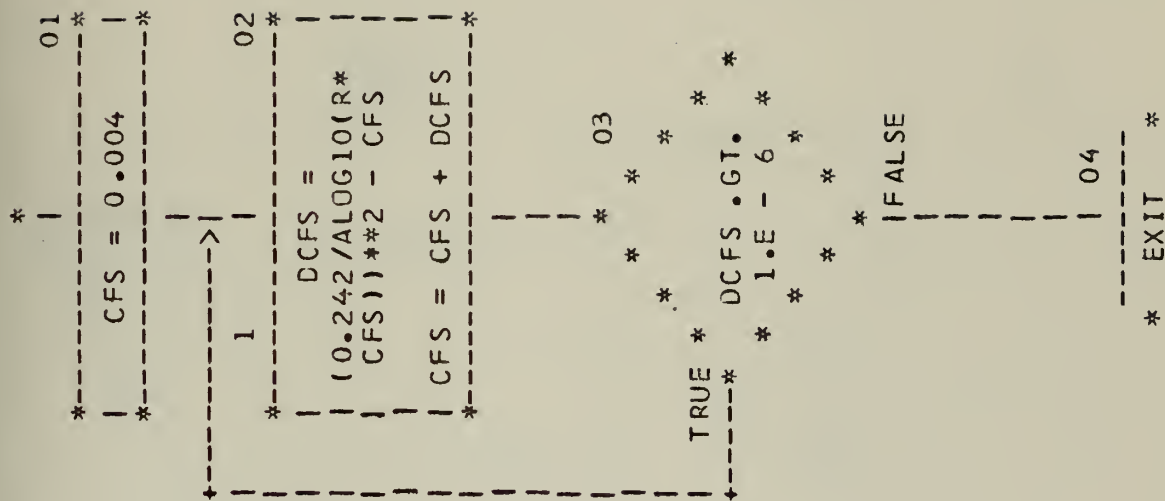
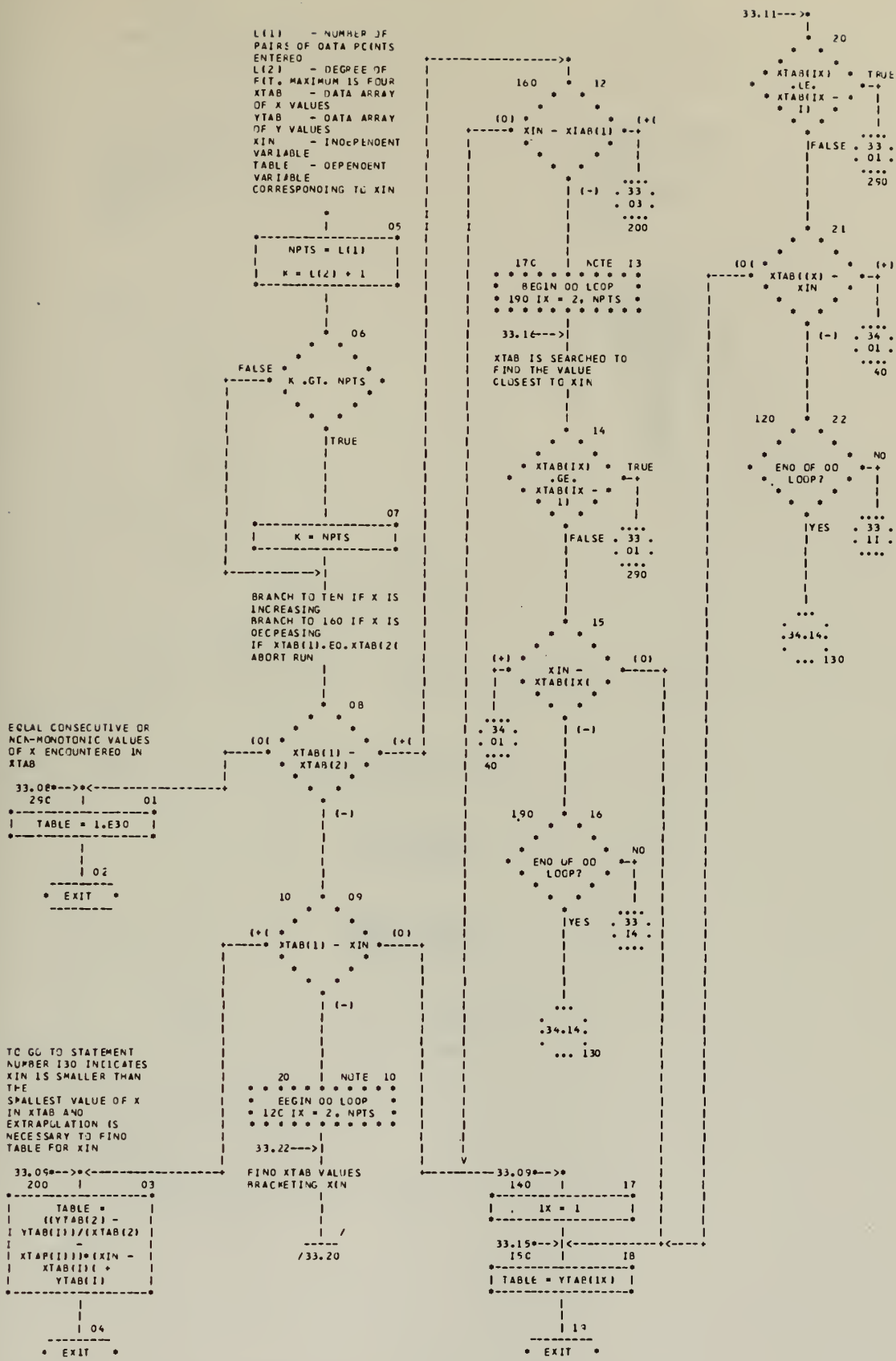


FIGURE 31. SUBROUTINE CFS FLOW DIAGRAM



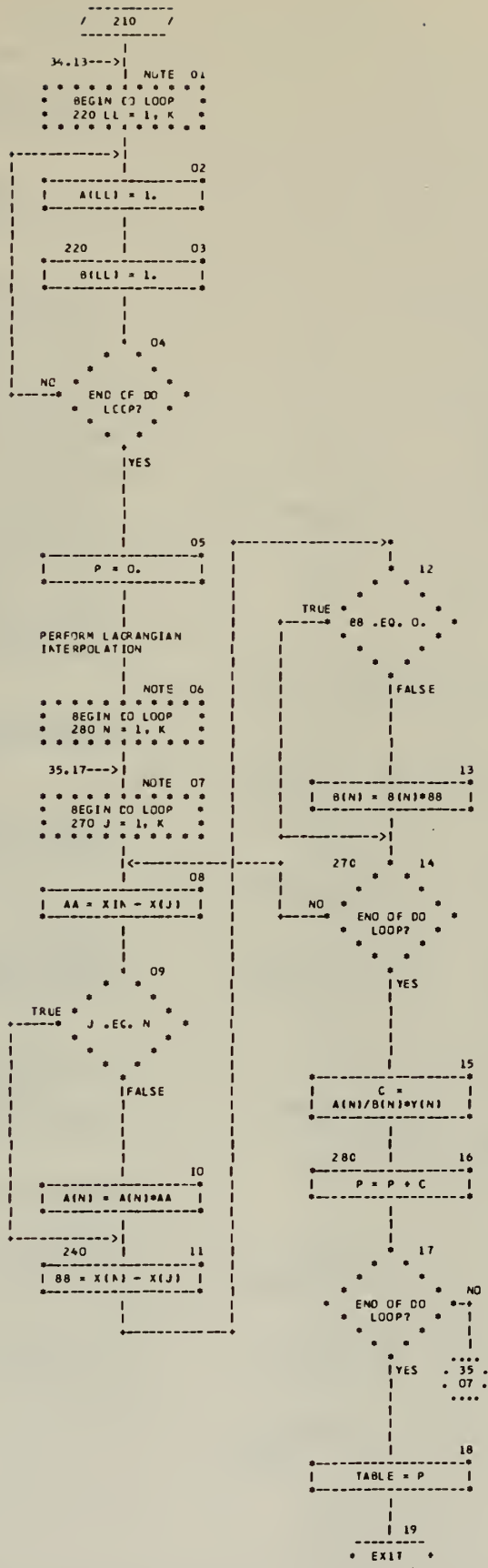


FIGURE 32 SUBROUTINE TABLE FLOW DIAGRAM (CONT.)

 / PTPN /

07.03--->*

SUBROUTINE PTPN
 PURPOSE
 TO FIND THE MINIMUM
 OF A FUNCTION BY
 DIRECT SEARCH

USAGE
 CALL
 PTPN(PSI,SPSI,N,FCT,
 DEL,DELMIN)

DESCRIPTION OF
 PARAMETERS
 PSI - A LINEAR
 ARRAY OF LENGTH N OF
 COORDINATES OF THE
 ORIGIN OF SEARCH,
 INPUT
 SPSI - THE MINIMUM
 VALUE OF THE
 FUNCTION, OUTPUT
 N - THE NUMBER OF
 PARAMETERS
 (COORDINATES) OF THE
 FUNCTION, INPUT
 FCT - THE FUNCTION
 SUBPROGRAM CONTAINING
 THE FUNCTION TO
 BE MINIMIZED
 DEL - A LINEAR
 ARRAY OF LENGTH N
 CONTAINING THE
 INITIAL
 STEP SIZE TO BE USED,
 INPUT
 DELMIN - A LINEAR
 ARRAY OF LENGTH N
 CONTAINING THE
 MINIMUM
 STEP SIZES TO BE
 USED, INPUT

SUBROUTINES AND
 FUNCTION SUBPROGRAMS
 REQUIRED
 FCT

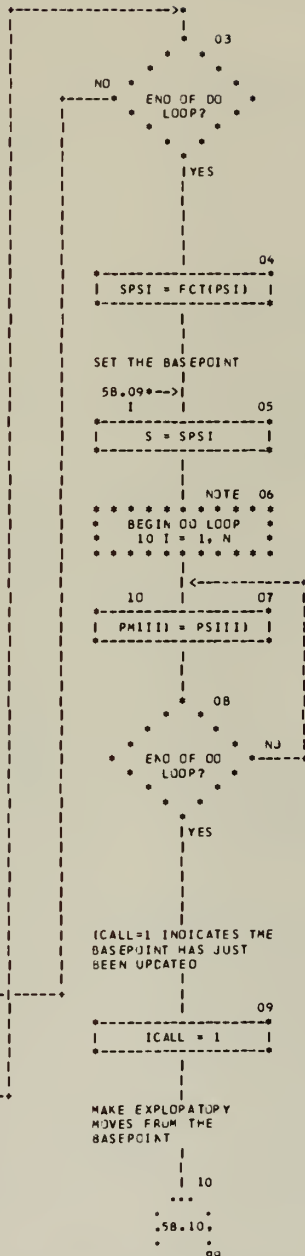
REMARKS
 THE CALLING PROGRAM
 MUST DECLARE THE
 FUNCTION SUBPROGRAM
 FCT IN AN EXTERNAL
 STATEMENT

THIS SUBROUTINE IS A
 MODIFIED VERSION OF
 THAT SUGGESTED BY
 HOOKE AND JEEVES AND
 FOLLOWS THE NOTATION
 OF THAT PAPER

REFERENCES
 1. HOOKE AND JEEVES,
 JACH, 8(2), APR 61, PP
 212-229
 2. ALGORITHM 178 AND
 SUBSEQUENT REMARKS,
 CACM

EVALUATE THE FUNCTION
 AT THE INITIAL POINT

NOTE 01
 BEGIN DO LOOP
 S K = 1, N
 DIPIK1 = 0.



STORE PREVIOUS POINTS

59.07--->*

2 | 11

SPSI = S

NOTE 12
 BEGIN DO LOOP
 I 1 = 1, N

THETA(I) = PSI(I)
 PSI(I) = PHI(I)

MAKE PATTERN MOVE
 I.E. SIMULTANEOUSLY
 MOVE THE DISTANCE
 FROM THE
 BASEPOINT TO THE
 PRESENT POINT IN EACH
 COORDINATE

PHI(I) = 2 * PHI(I) -
 THETA(I)

END OF DO LOOP?

SPMI = FCT(PHI)
 S = SPMI

ICALL = 2 INDICATES
 PATTERN MOVE JUST
 MADE

ICALL = 2

MAKE EXPLORATORY
 MOVES FROM RESULTING
 POINT OF PATTERN MOVE

... 99

FIGURE 33 SUBROUTINE PTPN FLOW DIAGRAM

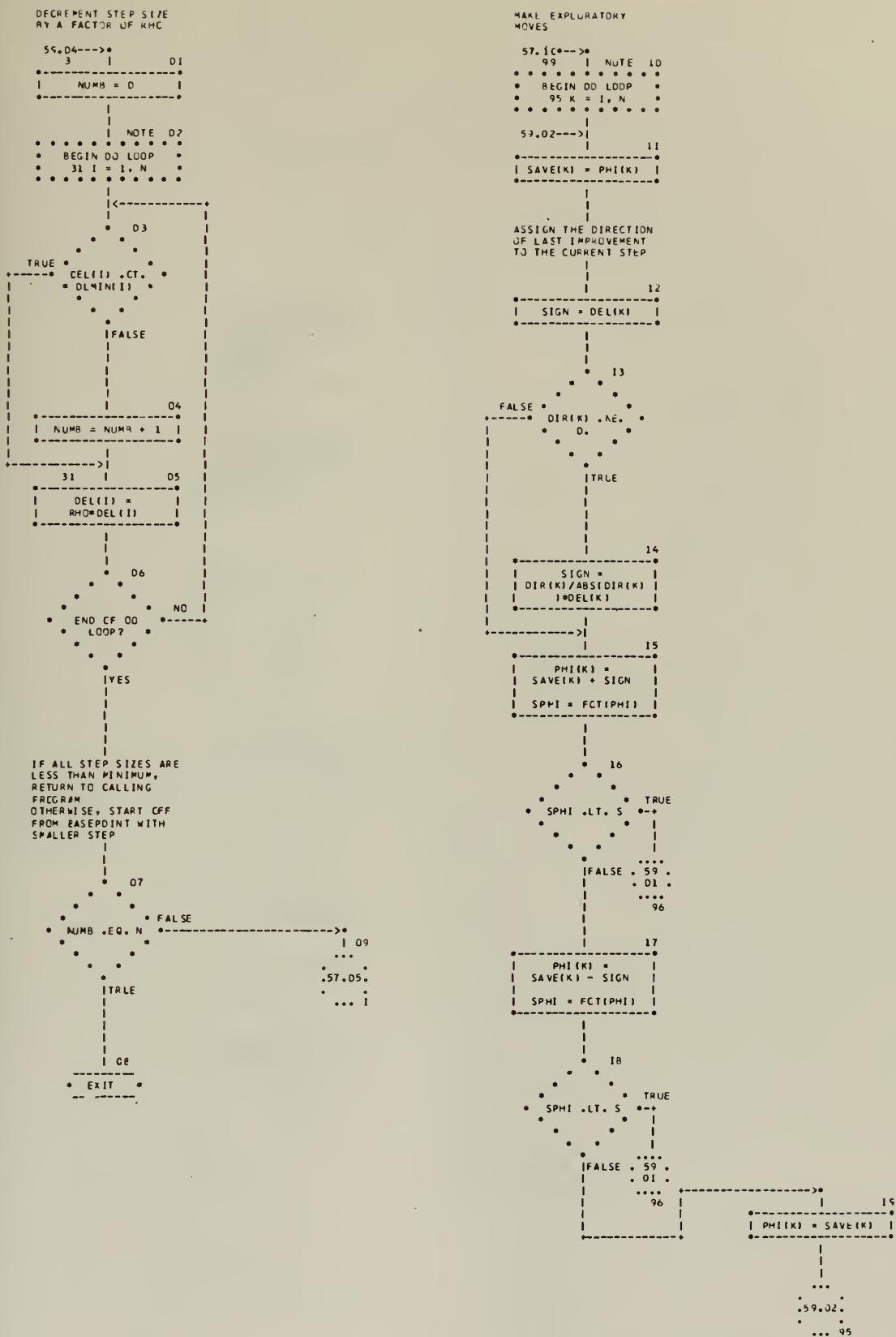


FIGURE 33 SUBROUTINE PTTN FLOW DIAGRAM (CONT.)

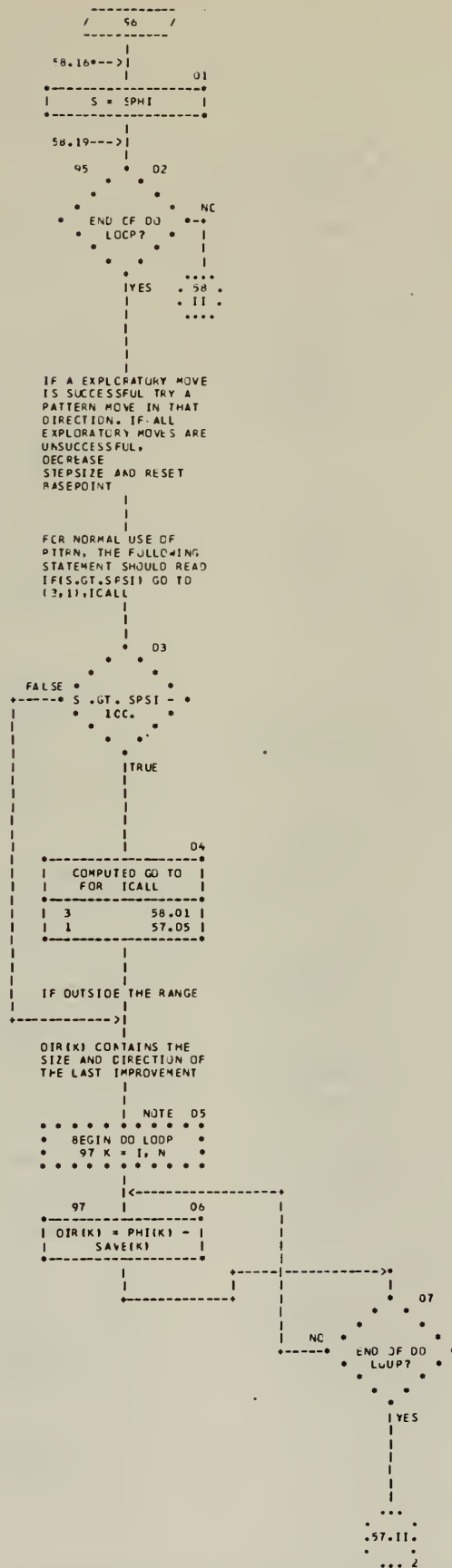
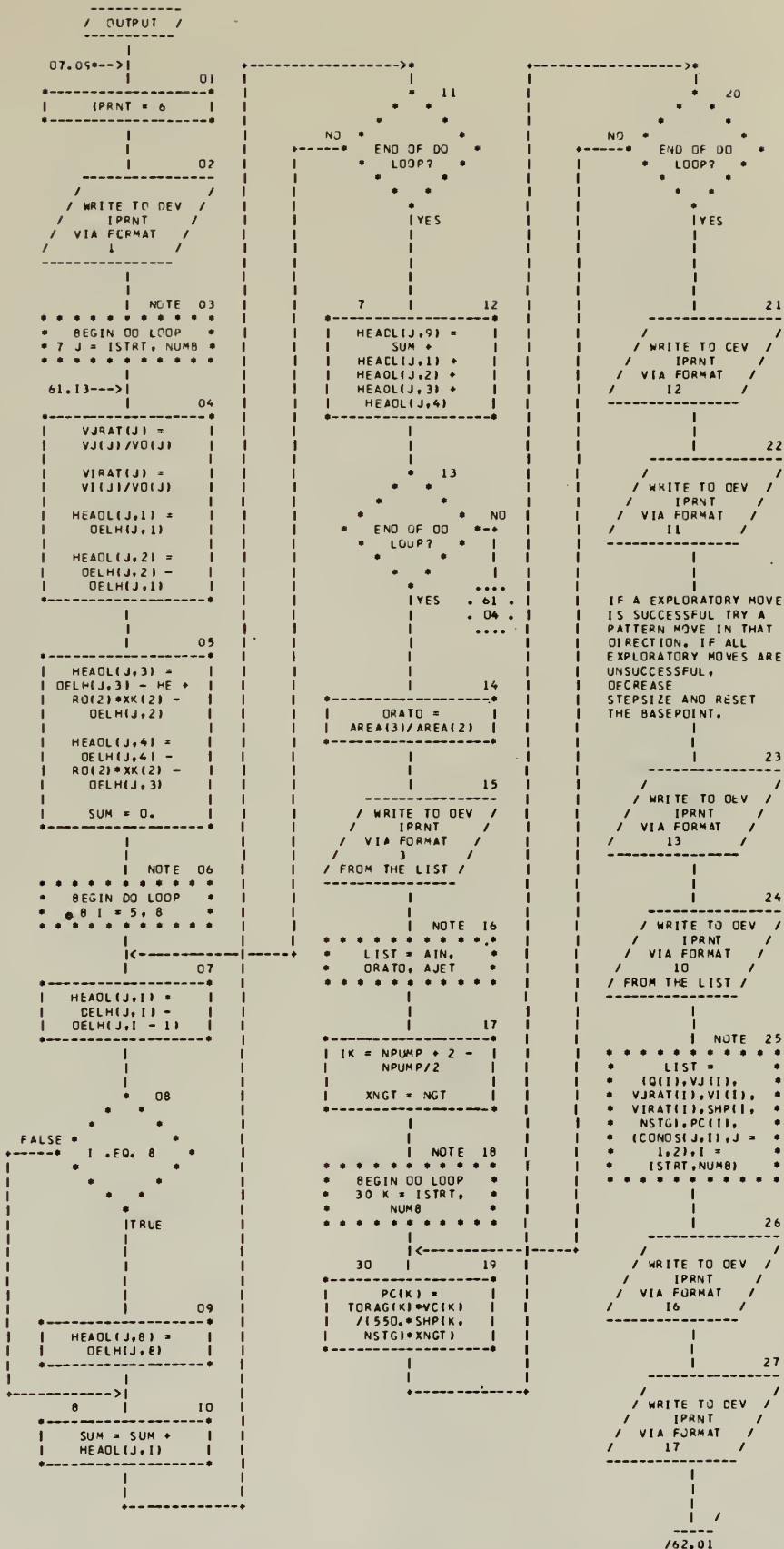


FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM
-149-



/62.01

FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)
-150-

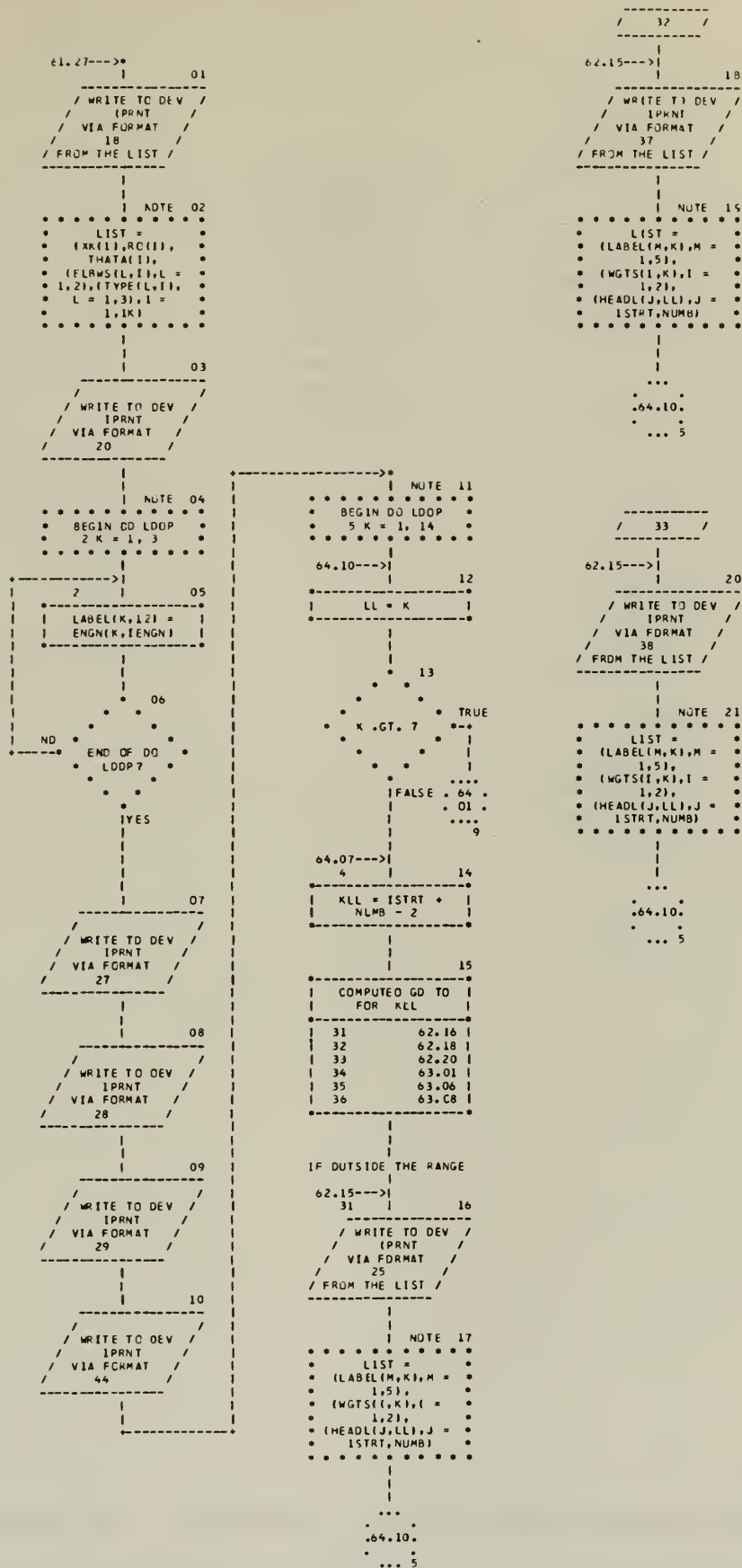


FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)
-151-

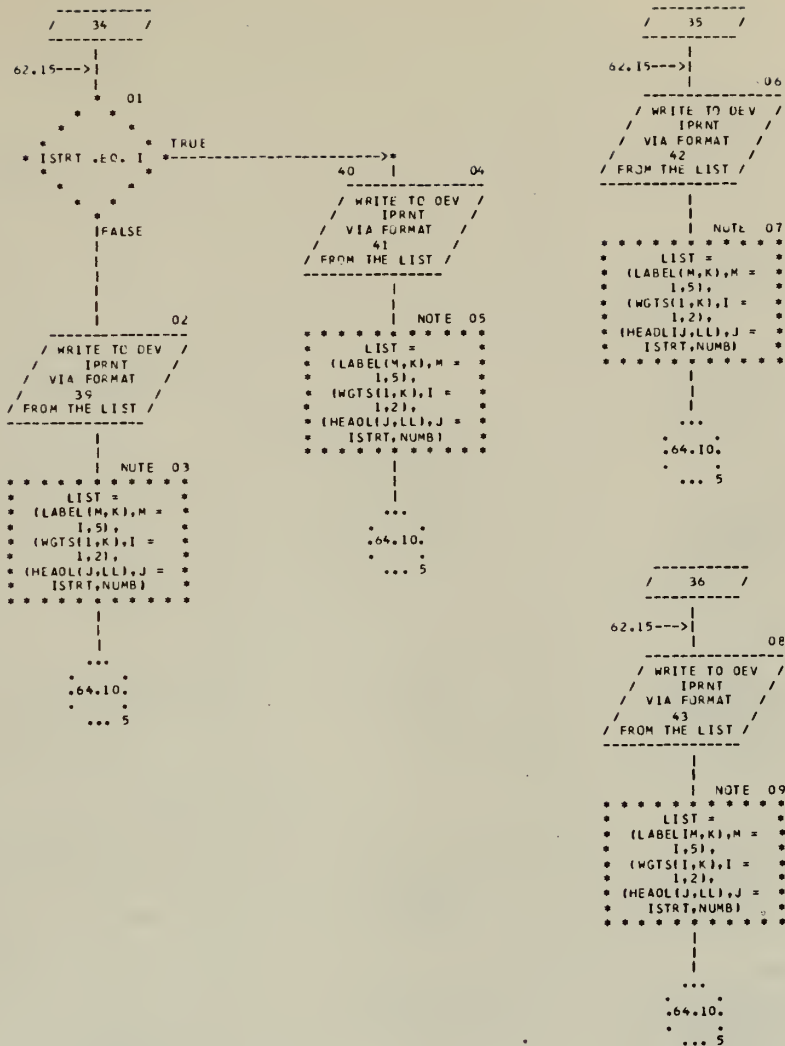


FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)

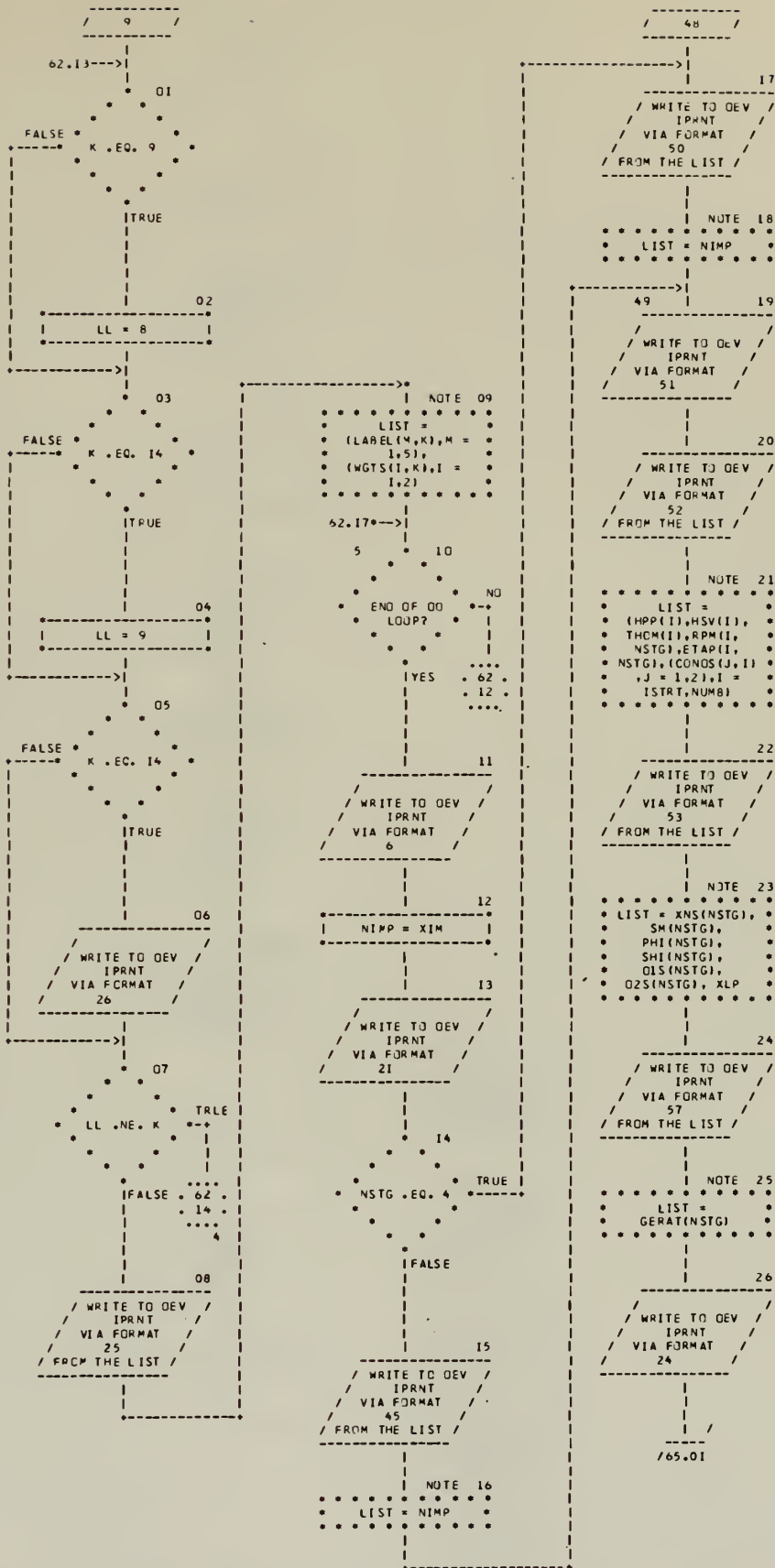


FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)



FIGURE 34 SUBROUTINE OUTPUT FLOW DIAGRAM (CONT.)


```

0001 LOGICAL IFUEL, IPUMP
0002 COMMON /CHARS/WGTS(2,15),CGS(4,15),DELU(5,15),CGSX,CGSZ
0003 COMMON /DRAG/TDRAG(5),STRD(5),PDD(5),SPRAY(5),PEST(5),VF(5),
0004
0005 1 TRIM(5)
0006 COMMON /H2O/TEMP,PV,PHOW,GMU,HA
0007 COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
0008 COMMON /CONST/PI,G,RHCD
0009 COMMON /FLDN/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
0010 COMMON /FLBW/XK(4),PD(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
0011 COMMON /INFX/IEVAL,IEQPT,ISTRT,NJMB,IENGN,ITYPE,ICOMP,NPUMP,NGT
0012 COMMON /ITABL/L(2)
0013 COMMON IFUEL,IPUMP
0014
0015 SAMPLE INPUT
0016
0017 VJ(1)=42.*1.4878
0018 REST(1)=71000.
0019 STRTD(1)=3500.
0020 PDD(1)=1750.
0021 SPRAY(1)=3000.
0022 PDD(2)=500.
0023 STRTD(2)=1000.
0024 VJ(2)=.5*VJ(1)
0025 SPRAY(2)=750.
0026 PEST(2)=00000.
0027 RANG=500.
0028 BEAM=42.
0029 IFNGN=11
0030 TRIM(1)=0.
0031 TRIM(2)=2.
0032 TEMP=52.
0033 DISP=99.*2240.
0034 CALL H2OJT
0035 STOP
0036 END

```

C
C
C


```

SUBROUTINE H2JT
LOGICAL IFUEL, IPUMP
COMMON /PARMS/ VJVE, VJVG, DIDM
COMMON /DPAG/DPAG(E), STPTQ(5), PJD(5), SPRAY(5), PEST(5), VJ(5),
1 TRIM(5)
COMMON /ELRW/XK(4), RD(4), THATA(4), WIDTH, DEPTH, TYPE(3,4)
COMMON /CHAPS/WGTS(2,15), CGS(4,15), DELH(5,15), CGSX, CGS7
COMMON /SHIP/ DISP, RANGE, BCAM, HS, HE, HCL, XLS, XLPE, XLP
COMMON /H2O/TEMP, PV, PHW, CNV, HA
COMMON /TEMPER/DELTA
COMMON /PSUB/GERAT(5), SHP(5,5), RPM(5,5), PERE(5,12), ETAP(8,5)
COMMON /CONST/ PI, G, RHO
COMMON /STRIC/TC, T, C, TL, CL, CFM
COMMON /INDEX/IEVAL, IEOPT, I STPT, NUMR, IENG, I TYPE, ICIMP, NPUMP, NGT
COMMON /ITABL/L(2)
COMMON IFUEL, IPUMP
EQUIVALENCE (VJVG, PARM(1))
DIMENSION PARM(3), ENGN(3,12), EHP(5), OFL(4), OLMIN(4)
DIMENSION VK(5)
EXTERNAL ECT
DATA IPRNT/4/
DATA ENGN/4HTE35,2*4H ,4HTE40,2*4H ,4HDECT, 4HEUS ,4H1500,
A 4HDECT,4HCHS ,4H1000, 4HTYNE, /H 1A ,4H ,4HTYNE,4H 1C ,4H
B 4HET12,4HA ,4H ,4HLM15,4H00 ,4H ,4HLM25,4H00 ,4H ,
C 4HET4A,4H-2C ,4H ,4HET4A,4H-12 ,4H ,4HET4C,4H-2 ,4H /
DATA OLMIN/4*.01/
IFUEL=.TRUE.
IPUMP=.FALSE.
DISP=DISP/2240.
DETERMINE ENGINE TYPE
IFENGN CONTAINS CODING OF GAS TURBINE MODEL
1 ENGN GAS TURBINE
2 TF35
TF40

```

```

H2JT001
H2JT002
H2JT003
H2JT004
H2JT005
H2JT006
H2JT007
H2JT008
H2JT009
H2JT010
H2JT011
H2JT012
H2JT013
H2JT014
H2JT015
H2JT016
H2JT017
H2JT018
H2JT019
H2JT020
H2JT021
H2JT022
H2JT023
H2JT024
H2JT025
H2JT026
H2JT027
H2JT028
H2JT029
H2JT030
H2JT031
H2JT032
H2JT033
H2JT034
H2JT035
H2JT036

```


H20JT037
H20JT038
H20JT039
H20JT040
H20JT041
H20JT042
H20JT043
H20JT044
H20JT045
H20JT046
H20JT047
H20JT048
H20JT049
H20JT050
H20JT051
H20JT052
H20JT053
H20JT054
H20JT055
H20JT056
H20JT057
H20JT058
H20JT059
H20JT060
H20JT061
H20JT062
H20JT063
H20JT064
H20JT065
H20JT066
H20JT067
H20JT068
H20JT069
H20JT070
H20JT071
H20JT072

PROTEUS 1500 RPM
PROTEUS 1000 RPM
TYNE 1A
TYNE 1C
FT12A
LM1500
LM2500
FT4A-2C
FT/A-12
FT4C-2

DETERMINE WHICH POINTS ARE INPUT

```

1  ISTRT=1
2  NUMR=2
3  IF (IEVAL.EQ.0) GO TO 3
4  NUMR=2+IAPS(IEVAL)
5  IF (IEVAL.LT.0) ISTRT=3
6  DO 1 I=ISTRT,NUMR
7    VK(I)=VQ(I)*.502487
8    TORAG(I)=PQ(I)+STRTD(I)+SPRAY(I)+REST(I)

```

IEVAL.LT.0 IMPLIES NO CRUISE OR TAKE-OFF POINTS SPECIFIED,
ARS(IEVAL) INDICATES HOW MANY POINTS FOR PERFORMANCE ESTIMATION
IEVAL.EQ.0 IMPLIES DESIGN AT CRUISE AND TAKE-OFF ONLY
IEVAL.GT.0 IMPLIES DESIGN AT CRUISE/TAKE-OFF AND ESTIMATE PERFORM.
AT IEVAL POINTS
IF ENTERED, CRUISE POINTS ARE IN FIRST POSITION IN ARRAY, TAKE-OFF
POINTS IN SECOND AND PERFORMANCE ESTIMATION POINTS IN REMAINING
POSITIONS
IEOPT NON-ZERO IMPLIES SPECIFIC TYPE EQUIPMENT TO BE INPUT BY USER
THIS SECTION OF THE PROGRAM TO BE WRITTEN LATER
IF (ISTRT.NE.1) GO TO 6
WRITE(IPRINT,5)
FORMAT(1H1,10X,5H *** WATERJET PROPUSSION SYSTEM DESIGN AND PERFORMANCE *** ///


```

WRITE(IPRNT,31)
WRITE(IPRNT,6)
4  FORMAT(12H OPERATIONAL,/)
WRITE(IPRNT,7)
7  FORMAT(30X,4HPULS,15X,8HTAKE-OFF,/)
WRITE(IPRNT,6) (VK(N),N=1,2)
8  FORMAT(14H VELOCITY, KNOTS,14X,F5.1,17X,F5.1)
WRITE(IPRNT,6) (TPDRAG(N),N=1,2)
9  FORMAT(14H TOTAL DRAG, LBS,13X,F7.0,15X,F7.0)
WRITE(IPRNT,10) (TRIM(N),N=1,2)
10  FORMAT(25H ANGLE OF ATTACK, DEGREES,6X,F4.1,13X,F4.1,/)
IF(IEVAL.EQ.0) GO TO 11
WRITE(IPRNT,12)
12  FORMAT(/,48H PERFORMANCE EVALUATION AT THE FOLLOWING POINTS,/)
GO TO 13
4  WRITE(IPRNT,14)
14  FORMAT(14H,10X,47H *** WATERJET PULSION SYSTEM PERFORMANCE ***
A ///)
13  JM=1ARS(IEVAL)
WRITE(IPRNT,6)
DO 15 I=1,IM
J=I+2
15  WRITE(IPRNT,16) VK(J),TPDRAG(J),TRIM(J)
16  FORMAT(16H VELOCITY, KNOTS,14X,F5.1,/,14H TOTAL DRAG,LBS,13X,F7.0,
A /,25H ANGLE OF ATTACK, DEGREES,6X,F4.1,/)
WRITE(IPRNT,31)
31  FORMAT(22H CRAFT CHARACTERISTICS,/)
11  WRITE(IPRNT,17)
17  FORMAT(14H CONFIGURATION,/)
WRITE(IPRNT,18) BEAM,DISPL,RANGE,(ENG(N),N=1,3)
18  FORMAT(28H AVERAGE BEAM, FEET....., F7.1,/,28H DISPLACEMENT,
A8H TNS....., F7.0,/,28H ENDURANCE, NM....., F7.0,/,28H GAH20JT104
A5  TURBINE PLANT.....,3X,3A4,/)
WRITE(IPRNT,19) HS,HE,HCL,XLS,XLDE
19  FORMAT(48H DEPTH OF SURMERCENCE OF NACELLE.....,F5.1,2XH20JT107
A,4HFEET,/,48H HEIGHT OF PUMP CENTERLINE ABOVE MEAN WATER.....,F5.1H20JT108

```



```

B,2X,4HEFT,/,40H HEIGHT OF PUMP CENTERLINE ABOVE KEEL....., H20JT1109
C55.1,2X,4HEFT,/,40H DISTANCE OF STRUT FROM TRANSOM....., H20JT1110
D,,,F5.1,2X,4HEFT,/,40H DISTANCE OF PUMP EXIT FROM TRANSOM....., H20JT1111
E.....,F5.1,2X,4HEFT,/, H20JT1112
WRITE(IPRNT,20) H20JT1113
20 FORMAT(10X,17H WATER PROPERTIES,/,10X,45H (ASSUMES STANDARD(3.5%
LALINITY) SALT WATER),/) H20JT1114
H20JT1115
H20JT1116
TEMP IS THE TEMPERATURE OF THE WATER IN DEGREES FAHRENHEIT H20JT1117
H20JT1118
25 PV=.11413E-7*TEMP**4+.1243E-6*TEMP**3+.49859E-4*TEMP*TEMP+.29710E H20JT1119
A-2*TEMP+.03233E H20JT1120
CNH=EXP(-.6201E-6*TEMP**3+.1740E-3*TEMP*TEMP-.02706*TEMP+1.414)* H20JT1121
A 1.E-5 H20JT1122
PHCW=(-.7906E-6*TEMP**4+.13714E-3*TEMP**3-.015082*TEMP*TEMP+.5517 H20JT1123
A*TEMP+56.569)/G H20JT1124
HA=2117.7/(RHCW*G) H20JT1125
WRITE(IPRNT,21) TEMP,RHOW,GNU,PV H20JT1126
21 FORMAT(32H TEMPERATURE, DEGREES FAHRENHEIT,5X,F4.0,/, H20JT1127
A 20H DENSITY, LBF-SEC**2/FEET**4,9X,F6.3,/, H20JT1128
B 31H VISCOSITY, *10**5, FEET**2/SEC,6X,5PF6.3,/, H20JT1129
C 21H VAPOR PRESSURE, FEET,15X,0PF6.3,/) H20JT1130
WRITE(IPRNT,22) G H20JT1131
22 FORMAT(36H ACCELERATION OF GRAVITY, FT/SECS**2,6X,F7.3,/) H20JT1132
IF(IFOPT.NE.0) GO TO 23 H20JT1133
WRITE(IPRNT,24) H20JT1134
24 FORMAT(49H NO EQUIPMENTS OR CONFIGURATIONS SPECIFIED. GENERATED AS H20JT1135
A PER PROGRAM,/,1H1) H20JT1136
GO TO 32 H20JT1137
33 WRITE(IPRNT,34) (ENGN(I,1)ENGN),I=1,3) H20JT1138
34 FORMAT(16H MORE THAN EQUIP,2A4,30H REQUIRED. INVALID PRIME MOVER) H20JT1139
RETURN H20JT1140
35 WRITE(IPRNT,36) H20JT1141
36 FORMAT(/,67HNOT ENGINE DRIVEN AT LESS THAN HALF DESIGN SHP. INVALID H20JT1142
10 PRIME MOVER,/) H20JT1143
RETURN H20JT1144

```



```

23 WRITE(IPRNT,26)
24 FORMAT(1H1, ' THE FOLLOWING EQUIPMENT, ETC. SPECIFIED.....')
C
C
C LATER THE SECTION FOR OUTPUTTING THE SPECIFIED EQUIPMENTS ETC WILL
C HAVE TO BE PUT IN HERE
C
C COMMENCE DESIGN/PERFORMANCE PREDICTION
C
C FIRST CHECK ON MINIMUM NUMBER OF GAS TURBINES REQUIRED, GIVEN THE
C TYPE AND EHP. THEN CYCLE THROUGH THE PUMP COMBINATIONS POSSIBLE.
C
32 IF(ISTPT.NE.1) GO TO 30
   IN=1
   MAX=3
   ISAVE=4
   XMIN=.25
   DO 37 IK=ISTPT,NUMB
     IL=1
     EHP(IK)=TOPAG(IK)*VDP(IK)/550.
     DO 37 IJ=1,3
       XJ=IJ+IJ/3
       IM=IK/3
       MK=IK-IM*(IK-2)
       IF(1.5*EHP(IK).GT.XJ*PERF(MK,IENGNI)) IL=IJ+1
       IF(IK.GT.1) GO TO 30
       IF(EHP(IK)/XJ.LT.XMIN*PERF(1,IENGNI)) ISAVE=XJ*.5
       IF(ISAVE.LT.MAX) MAX=ISAVE
       IF(MAX.EQ.0) GO TO 35
33 IF(IL.GT.3) GO TO 33
37 IF(IM.LT.IL) IN=IL
   DO 30 IK=IN,MAX
C
C PUT MIN NUMBER GT'S REQUIRED IN HERE
   NGT=IK+IK/3
   KM=NGT/4+1
H20JT145
H20JT146
H20JT147
H20JT148
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H20JT202
H20JT203
H20JT204
H20JT205
H20JT206
H20JT207
H20JT208
H20JT209

```

K1=2*IK-NGT+1
DO 20 I=KM,K1
  DELTA=.05
  DEL(1)=.5
  DEL(2)=.2
  DEL(3)=.3
  NPUMP=I+I/3
  VIVQ=1.9
  VIVQ=.7
  CIRM=.7
  CALL PTEN(PARM,WEIGHT,3,FCT,DEL,DLMIN)
  DELTA=0.0
  WEIGHT=FCT(PARM)/2240.
  WRITE(IPRNT,50) WEIGHT
50  FORMAT(10X,21H*** SYSTEM WEIGHT IS ,F10.2,9H TONS ***)
  WRITE(IPRNT,51) NGT,NPUMP
51  FORMAT(//,27H NUMBER OF GAS TURBINES IS ,I2,/,20H NUMBER OF PUMPS
      AIS ,I2,/)
  CALL OUTPUT
28  CONTINUE
30  CONTINUE
  IF(NUMB.CO.2) RETURN
  ISTAT=3
38  WEIGHT=FCT(PARM)/2240.
  WRITE(IPRNT,50) WEIGHT
  WRITE(IPRNT,51) NGT,NPUMP
  CALL OUTPUT
  RETURN
END

```



```

FUNCTION FCT(PARM)
LOGICAL IFUEL, IPUMP
COMMON /CHARS/NGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
COMMON /PSUR/GFRAT(5),SHD(5,5),PDM(5,5),PERF(5,12),ETAP(8,5)
COMMON /H2O/TMP,PV,RH2O,GNH,HA
COMMON /ELRW/XK(4),CO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
COMMON /SHIP/ DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
COMMON /NACLI/CRAT,DM,AI,ALAUX,ELEXT,ELENT,FLAUX,FLDIF,FLN
COMMON /FLOW/O(5),AIN,AJET,AREA(11),VJ(5),VI(5)
COMMON /CONST/PI,G,RHCD
COMMON /PUMM/CO(5),DIS(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5),
A XIM
COMMON /DRAC /TDRAG(5),STRTO(5),POD(5),SPRAY(5),PEST(5),VO(5),
1 TRIM(5)
COMMON /CDRAG/CSTRT(5),CPID(5),CSPRY(5)
COMMON /TOLEP/ DELTA
COMMON /INDEX/IEVAL, IEQPT, ISTRT, NUMR, IENG, I TYPE, ICDNO, NPUMP, NGT
COMMON /ITAP/L(2)
COMMON IFUEL, IPUMP
DIMENSION PARM(7),APDC(5),ASTRT(5),ASPRY(5),C(5),DDRAG(5),DSPRY(5)
A ,CSTRT(5),CPID(5)
DATA C/1.,1.25,3#1./
IF(.NOT.IPUMP) XLP=5.
TSUM=1.E50

DOO BACK TO OPTIMIZATION IF ROUNDS EXCEEDED

IF(PARM(1).GT.5..AND.DELTA.GT.1.E-9) GO TO 8
IF(PARM(1).LT.1.1) GO TO 8
IF(PARM(2).LT.5) GO TO 8
IF(PARM(2).GT.1.5) GO TO 8
IF(PARM(3).GT.9) GO TO 8
IF(PARM(3).LT.5.0..AND.DELTA.GT.1.E-9) GO TO 8
DRAT=PAFM(3)
DO 15 J=ISTRTO,NUMR
CSTRT(J)=STRTO(J)

```



```

0000(J)=PDC(J)
0001(J)=SPRAY(J)
0002(J)=TORAG(J)
0003(VJ(1)=VJ(1)*PARM(1)
0004(VI(1)=VJ(1)*PARM(2)
0005 ANGLE=ATAN(TORAG(1)/DISP)
0006 IF(TORAG(1)/DISP.GT..2.AND.DELTA.GT.1.E-9) GO TO 8
0007 IF(TORAG(1)/DISP.LT..05.AND.DELTA.GT.1.E-9) GO TO 8
0008 CDEF=1.
0009 Q(1)=TORAG(1)/(RHO*(VJ(1)*COS(ANGLE)-VJ(1)))
0010 AIN=Q(1)/VI(1)
0011 AJET=Q(1)/VJ(1)
0012 I=2
0013 IF(I.STRT.EQ.3) I=3
0014 DO 5 J=1,NUMB
0015 SPD=.F*VC(J)/COS(ANGLE)
0016 VJ(J)=SPD+SQRT(SPD*SPD+C(J)*TORAG(J)/(RHO*AJET*COS(ANGLE)))
0017 Q(J)=AJET*VJ(J)
0018 VI(J)=Q(J)/AIN
0019 ICOMP=1
0020 CALL NACEL
0021 IF(WGTS(1,1).GT.DISP.AND.DELTA.GT.1.E-9) GO TO 8
0022 ICOMP=2
0023 DEPTH=SQRT(AREA(1))
0024 WIDTH=.5*DEPTH
0025 CALL CLROW
0026 CGS(1,ICOMP)=HCL-HF-HS
0027 CGS(2,ICOMP)=XLS+(HE-RD(1)*XK(1)+HS)/TAN(THATA(2)*.0174533)
0028 WGTS(1,ICOMP)=WGTS(1,ICOMP)*(PHDO-RHOW)/RHOD
0029 WGTS(2,ICOMP)=0.
0030 ICOMP=3
0031 CALL STPUT
0032 J=NUMB
0033 IF(I.STRT.EQ.1) J=2

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-163-

IF NEWLY COMPUTED DRAG DIFFERS SIGNIFICANTLY (I.E. GREATER

SIZE IS NEWLY COMPUTED DPAG DIFFERS SIGNIFICANTLY (I.E. GREATER


```

C      THAN 5%) FROM PREVIOUS ESTIMATE. IF SO, RECOMPUTE ON BASIS OF NEW
C      DRAG. OTHERWISE CONTINUE.
C
      JDPAG=1
      DO 9 I=1,ISTRT,J
      APD(I)=CDEF*(CPD(I)-PDD(I))
      ASTPT(I)=CSTRT(I)-STRTD(I)
      ASPRY(I)=CSPRY(I)-SPRAY(I)
      IF(ARS(APD(I)+ASTPT(I)+ASPRY(I)).GE..05*TDPRAG(I)) JDPAG=2
      CSPRY(I)=CSPRY(I)
      STRTD(I)=CSTRT(I)
      PDD(I)=CPD(I)
      9 TORAG(I)=PEST(I)+PDD(I)+STRTD(I)+SPRAY(I)
      IF(JDRAG.EQ.2) GO TO 10
      ICOMP=4
      CALL ELROW
      CGS(1,ICOMP)=HCL
      CGS(2,ICOMP)=XLS
      CGS(3,ICOMP)=CGS(1,ICOMP)
      CGS(4,ICOMP)=XLS
      ICOMP=5
      GO TO (1,2,3,3),NPUMP
      1 CALL JUNCT
      GO TO 6
      2 CALL PIPE
      GO TO 4
      3 CALL OIVRG
      4 ICOMP=9
      DSIG=4.
      DO 13 KOUNT=1,ISTRT,NUMP
      TOTAL=V2(KOUNT)**2/G*.5-DELH(KOUNT,6)-PV+HA
      SIGMA=TOTAL-(Q(KOUNT)/AREA(6))**2*.5/G
      IF(SIGMA.GT.0.) GO TO 13
      IF(SIGMA.GT.DSIG) GO TO 13
      CDEF=0.
      DSIG=SIGMA

```



```

AREA(4)=1.05*Q(KOUNT)/SQRT(2.*G*TOTAL)
13 CONTINUE
IF(OSIG.NE.4.) GO TO 12
14 CONTINUE
CALL NG77L
IF(WGTS(1,ICOMP).GT.DISP.AND.DELTA.GT.1.E-9) GO TO 8
ICOMP=0
CALL PUMP
IF(IPUMP) NNSTG=NSTG
IF(IPUMP) GO TO 12
IF(NNSTG.NE.NSTG.AND.DELTA.LT.1.E-9) IPUMP=.TRUE.
IF(NNSTG.NE.NSTG.AND.DELTA.LT.1.E-9) GO TO 12
DO 11 J=1,ISTRT,NUMB
11 DELH(J,0)=DELH(J,7)+DELH(J,8)
7SUM=0.
XSUM=0.
TSUM=0.
WGTS(1,12)=PERE(5,1*ENG)*ELUAT(NGT)
DO 6 J=1,2
SUM=0.
SUMX=0.
SUM7=0.
DO 7 I=1,12
SUMZ=SUM7+WGTS(J,I)*CGS(2*J-1,I)
SUMX=SUMX+WGTS(J,I)*CGS(2*J,I)
7 SUM=SUM+WGTS(J,I)
WGTS(J,14)=SUM
CGS(2*J-1,13)=SUM7/SUM
CGS(2*J,13)=SUMX/SUM
TSUM=TSUM+SUM
XSUM=XSUM+SUMX
ZSUM=ZSUM+SUM7
CGSX=XSUM/TSUM
CGSZ=ZSUM/TSUM
WGTS(2,13)=-RHOW*Q(1)*VJ(1)*SIN(ANGLE)
WGTS(2,14)=WGTS(2,14)+WGTS(2,13)
FCT 0108
FCT 0109
FCT 0110
FCT 0111
FCT 0112
FCT 0113
FCT 0114
FCT 0115
FCT 0116
FCT 0117
FCT 0118
FCT 0119
FCT 0120
FCT 0121
FCT 0122
FCT 0123
FCT 0124
FCT 0125
FCT 0126
FCT 0127
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FCT 0129
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FCT 0141
FCT 0142
FCT 0143

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FCT 0144
 FCT 0145
 FCT 0146
 FCT 0147
 FCT 0148
 FCT 0149
 FCT 0150
 FCT 0151
 FCT 0152

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8  FCT=TSUM+WGT5(2,13)
   IF(FCT.IT.NTSP.OR.DELTA.LT.1.E-5) RETURN
   DO 14 I=1STRT,NUMR
     SPRAY(I)=DSPEY(I)
     PCN(I)=DPCN(I)
     STRTD(I)=DSTRT(I)
16  TRAG(I)=DTRAG(I)
     RETURN
   FND
  
```


SUBROUTINE MACEL
 COMMON / WARM / CAV (5)
 COMMON / H2O / TEMP, PV, RHO, GNU, HA
 COMMON / SHIP / DISP, RANGE, BEAM, HS, HE, HCL, XLS, XLPE, XLP
 COMMON / CONECT / PI, G, RHOD
 COMMON / CHAR S / WGT S (2, 15), CGS (4, 15), DELH (5, 15), CGSX, CGSZ
 COMMON / FLOW / Q (5), AIN, AJET, APEA (11), VJ (5), VI (5)
 COMMON / INDEX / IEVAL, IEQPT, ISTRT, NJMB, IENGN, ITYPE, ICOMP, NPUMP, NGT
 COMMON / DRAG / TORAG (5), STRID (5), PCO (5), SPRAY (5), REST (5), VC (5),
 1 TRIM (5)
 COMMON / CDPRAG / CSTRT (5), CPPO (5), CSPRY (5)
 COMMON / ICLEF / DELTA
 COMMON / NACL / DRAT, DM, AI, AIAUX, FLEXT, ELENT, ELAUX, ELDIR, FLN
 COMMON / ELRW / XK (4), RG (4), THATA (4), WIDTH, DEPTH, TYPE (3, 4)
 DIMENSION NL (2), ML (2), KL (2), JL (2), IL (2)
 DIMENSION AA (30), AB (30), AC (30), AD (30), AE (30), AF (30), AG (30), AH (30)
 DIMENSION BA (30), BB (30), BC (30), BD (30), BE (30), BF (30), BG (30), BH (30)
 DIMENSION ALFAT (4), VRT (6), XDT (10), CPINT (6, 10, 4), CPEXT (6, 10, 4),
 1 PRLT (4), SISI (5), PTQ (5), XDTT (4), COUNX (10), COJMY (10), AT (2), CO (5)
 2, DIDMT (10), VRTT (4), DLI (5), DLI (5), VLEF (5), VRTX (4), VMAX (5)
 EQUIVALENCE (CPINT (1, 1, 1), AA (1)), (CPINT (1, 6, 1), AB (1)), (CPINT (1, 1, 2),
 1), AC (1)), (CPINT (1, 6, 2), AD (1)), (CPINT (1, 1, 3), AE (1)), (CPINT (1, 6, 3),
 2), AF (1)), (CPINT (1, 1, 4), AG (1)), (CPINT (1, 6, 4), AH (1)), (CPEXT (1, 1, 1), BA
 3), (CPEXT (1, 6, 1), BB (1)), (CPEXT (1, 1, 2), BC (1)), (CPEXT (1, 6, 2), BD (1)),
 4, (CPEXT (1, 1, 3), BE (1)), (CPEXT (1, 6, 3), BF (1)), (CPEXT (1, 1, 4), BG (1)),
 5, (CPEXT (1, 6, 4), BH (1))
 EQUIVALENCE (AT (1), ALFAT (1)), (DRAT, DIDMT)
 DATA NL, ML, KL, JL / 6, 2, 2, 2, 10, 3, 6, 3 /, IL / 4, 2 /
 DATA PRLT / 0.973, 0.963, 0.962, 0.945, 0.928, 0.909 /
 DATA ALFAT / 0.0, 2.0, 4.0, 6.0 /,
 1 XDT / 0.25, 0.50, 0.75, 1.0, 1.25, 1.50, 1.75, 2.0, 2.25, 2.5 /, DIDMT / 0.810,
 2 0.605, 0.427, 0.577, 0.533, 0.490, 0.439, 0.365, 0.260, 0.090 /
 3, VRT / .7, .8, .9, 1.05, 1.15, 1.25 /
 DATA AA /
 A 0.170 , -0.150 , -0.540 , -1.300 , -1.980 , -2.770 ,
 B 0.247 , 0.010 , -0.300 , -0.860 , -1.330 , -1.925 ,

C	0.335	, 0.125	, -0.145	, -0.605	, -0.965	, -1.415	, NACEL036
D	0.378	, 0.175	, -0.055	, -0.470	, -0.775	, -1.120	, NACEL037
E	0.403	, 0.212	, -0.005	, -0.333	, -0.665	, -0.975	, NACEL038
DATA AB/							
A	0.413	, 0.233	, 0.026	, -0.333	, -0.510	, -0.887	, NACEL040
B	0.417	, 0.245	, 0.053	, -0.302	, -0.506	, -0.832	, NACEL041
C	0.419	, 0.254	, 0.071	, -0.278	, -0.502	, -0.780	, NACEL042
D	0.420	, 0.262	, 0.082	, -0.259	, -0.499	, -0.752	, NACEL043
E	0.421	, 0.271	, 0.090	, -0.241	, -0.480	, -0.720	, NACEL044
DATA AC/							
A	0.000	, -0.360	, -0.900	, -1.570	, -2.430	, -3.900	, NACEL046
B	0.157	, -0.125	, -0.475	, -1.118	, -1.630	, -2.750	, NACEL047
C	0.240	, 0.018	, -0.258	, -0.788	, -1.075	, -1.670	, NACEL048
D	0.328	, 0.102	, -0.130	, -0.583	, -0.930	, -1.250	, NACEL049
E	0.345	, 0.140	, -0.060	, -0.464	, -0.770	, -1.020	, NACEL050
DATA AD/							
A	0.386	, 0.106	, -0.018	, -0.385	, -0.664	, -0.902	, NACEL051
B	0.308	, 0.220	, 0.011	, -0.330	, -0.595	, -0.836	, NACEL052
C	0.407	, 0.238	, 0.034	, -0.287	, -0.545	, -0.780	, NACEL054
D	0.414	, 0.252	, 0.055	, -0.258	, -0.507	, -0.766	, NACEL055
E	0.417	, 0.263	, 0.071	, -0.222	, -0.492	, -0.742	, NACEL056
DATA AE/							
A	-0.215	, -0.590	, -1.140	, -2.150	, -3.150	, -4.450	, NACEL057
B	0.020	, -0.205	, -0.700	, -1.465	, -2.195	, -3.240	, NACEL058
C	0.160	, -0.105	, -0.408	, -0.980	, -1.450	, -2.000	, NACEL060
D	0.255	, 0.010	, -0.255	, -0.710	, -1.070	, -1.455	, NACEL061
E	0.310	, 0.088	, -0.145	, -0.554	, -0.860	, -1.180	, NACEL062
DATA AF/							
A	0.345	, 0.152	, -0.075	, -0.450	, -0.725	, -1.024	, NACEL063
B	0.367	, 0.200	, -0.030	, -0.383	, -0.643	, -0.930	, NACEL064
C	0.385	, 0.225	, 0.012	, -0.328	, -0.589	, -0.880	, NACEL065
D	0.401	, 0.243	, 0.048	, -0.280	, -0.541	, -0.850	, NACEL066
E	0.412	, 0.258	, 0.060	, -0.245	, -0.509	, -0.820	, NACEL067
DATA AG/							
A	-0.550	, -0.950	, -1.600	, -2.840	, -3.500	, -5.200	, NACEL069
B	-0.250	, -0.570	, -1.020	, -1.900	, -2.650	, -3.920	, NACEL070
							, NACEL071

C	0.000	, -0.275	, -0.600	, -1.230	, -1.770	, -2.385	, NACEL072
D	0.150	, -0.065	, -0.340	, -0.350	, -1.365	, -1.860	, NACEL073
F	0.255	, 0.020	, -0.200	, -0.800	, -1.215	, -1.800	, NACEL074
DATA AH/							
A	0.315	, 0.120	, -0.110	, -0.685	, -1.130	, -1.715	, NACEL075
B	0.355	, 0.173	, -0.050	, -0.614	, -1.097	, -1.665	, NACEL076
C	0.375	, 0.195	, 0.002	, -0.575	, -1.060	, -1.640	, NACEL077
D	0.392	, 0.225	, 0.032	, -0.545	, -1.035	, -1.625	, NACEL078
E	0.405	, 0.248	, 0.060	, -0.520	, -1.017	, -1.617	, NACEL079
DATA BA/							
A	-0.485	, -0.660	, -0.450	, -0.410	, -0.400	, -0.385	, NACEL080
B	-0.335	, -0.330	, -0.315	, -0.300	, -0.295	, -0.280	, NACEL081
C	-0.240	, -0.230	, -0.230	, -0.225	, -0.220	, -0.215	, NACEL082
D	-0.175	, -0.185	, -0.170	, -0.170	, -0.165	, -0.164	, NACEL083
E	-0.140	, -0.145	, -0.135	, -0.140	, -0.135	, -0.135	, NACEL084
DATA BR/							
A	-0.115	, -0.120	, -0.110	, -0.115	, -0.110	, -0.115	, NACEL085
B	-0.100	, -0.105	, -0.100	, -0.100	, -0.100	, -0.100	, NACEL086
C	-0.093	, -0.095	, -0.095	, -0.095	, -0.092	, -0.095	, NACEL087
D	-0.090	, -0.090	, -0.090	, -0.090	, -0.090	, -0.090	, NACEL088
E	-0.088	, -0.088	, -0.088	, -0.088	, -0.088	, -0.088	, NACEL089
DATA PC/							
A	-0.540	, -0.500	, -0.460	, -0.460	, -0.410	, -0.435	, NACEL090
B	-0.365	, -0.350	, -0.335	, -0.320	, -0.305	, -0.305	, NACEL091
C	-0.270	, -0.265	, -0.245	, -0.235	, -0.230	, -0.230	, NACEL092
D	-0.205	, -0.205	, -0.185	, -0.175	, -0.175	, -0.180	, NACEL093
E	-0.165	, -0.160	, -0.145	, -0.140	, -0.140	, -0.145	, NACEL094
DATA BN/							
A	-0.140	, -0.130	, -0.120	, -0.115	, -0.115	, -0.120	, NACEL095
B	-0.125	, -0.110	, -0.105	, -0.100	, -0.100	, -0.105	, NACEL096
C	-0.115	, -0.095	, -0.095	, -0.095	, -0.092	, -0.095	, NACEL097
D	-0.110	, -0.090	, -0.090	, -0.090	, -0.090	, -0.090	, NACEL098
E	-0.105	, -0.095	, -0.085	, -0.085	, -0.089	, -0.085	, NACEL099
DATA BT/							
A	-0.505	, -0.535	, -0.535	, -0.460	, -0.445	, -0.445	, NACEL100
B	-0.420	, -0.390	, -0.370	, -0.350	, -0.335	, -0.330	, NACEL101

NACEL108
 NACEL109
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 NACEL134
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 NACEL142
 NACEL143

C -0.330 , -0.310 , -0.275 , -0.260 , -0.260 ,
 D -0.275 , -0.265 , -0.215 , -0.205 , -0.195 ,
 E -0.250 , -0.230 , -0.175 , -0.165 , -0.160 ,
 DATA RE/
 A -0.235 , -0.205 , -0.145 , -0.140 , -0.138 ,
 R -0.235 , -0.185 , -0.135 , -0.125 , -0.125 ,
 C -0.240 , -0.170 , -0.125 , -0.120 , -0.118 ,
 D -0.250 , -0.155 , -0.120 , -0.115 , -0.113 ,
 E -0.265 , -0.145 , -0.118 , -0.112 , -0.110 ,
 DATA RG/
 A -0.670 , -0.610 , -0.570 , -0.525 , -0.475 ,
 R -0.485 , -0.460 , -0.415 , -0.380 , -0.365 ,
 C -0.375 , -0.373 , -0.335 , -0.293 , -0.285 ,
 D -0.378 , -0.322 , -0.285 , -0.235 , -0.232 ,
 E -0.331 , -0.300 , -0.255 , -0.200 , -0.195 ,
 DATA RH/
 A -0.337 , -0.285 , -0.238 , -0.176 , -0.171 ,
 R -0.340 , -0.300 , -0.231 , -0.163 , -0.157 ,
 C -0.400 , -0.310 , -0.230 , -0.157 , -0.145 ,
 D -0.427 , -0.322 , -0.229 , -0.155 , -0.139 ,
 E -0.409 , -0.336 , -0.230 , -0.153 , -0.135 ,
 FRICT(RG)=(.85850*ALOG(RE/(1.064*ALOG(RE)-3.8215)))*(-2)

-170-

7K IS THE DECIMAL PART OF THE ANNULUS OCCUPIED BY THE
 AUXILIARY INLET THAT IS ACTUALLY OPENING. THE REMAINDER IS
 STRUCTURE.

7K=.9
 SPC=(HS+HA)*RHJW*G
 PVP=DV*RHJW*G
 VELP(1)=VI(1)/VVO(1)

SIGTV IS THE INCIPIENT CAVITATION NO. ON THE ELBOW TURNING
 VANES REFERENCED TO DIFFUSER EXIT PRESSURE AND VELOCITY.

SIGTV=0.4

C
C
C
C
C

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C

[illegible]

[illegible]

NACEL216
 NACEL217
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 NACEL248
 NACEL249
 NACEL250
 NACEL251

```

QIN=AI*VRMAX(2)*V(2)
QC=0.5*Q(2)
QAUX=QC-QIN
IF(QAUX.LF.0.)QAUX=0.
QIN=QC-QAUX
KDE X=0
C CALCULATE STATIC PRESSURE IMMEDIATELY AFT. OF THE LIP.
VI2=QIN/AI
VR=VI2/V(2)
PRL2=TABLE(VRT,PRLT,VR,JL)
PTI=PRL2*Q(2)+SPQ
SPI=PTI-0.5*RHQW*VI2*VI2
C CALCULATE COMBINED FLOW PRESSURES AND AUX. INLET AREA.
AIAUX=0.
VIAUX=0.
PTAUX=0.
IF(QAUX.EQ.0.)GO TO 12
PRAUX=0.90
PTAUX=PRAUX*QC(2)+SPQ
PDYP=PTAUX-SPI
VIAUX=SQRT(2.*DYP/RHAW)
AIAUX=QAUX/VIAUX
12 CONTINUE

C THE TOTAL PRESSURE OF THE COMBINED FLOW IS CALCULATED AS THE
C MASS WEIGHTED AVERAGE OF THE COMBINING FLOWS.
PC=(PTI*QIN+PTAUX*QAUX)/QC
VI(2)=SQRT(2.*(PC-SPI)/RHAW)
CLIP(2)=1.-(PC-SPQ)/QC(2)
QDIF=QC

C CALCULATE THE INTERNAL LENGTHS TO THE DIFFUSER ENTRY.
ELENT=ELEXT/2.
PHI=ATAN(.5*(DM-DI)/ELEXT)

```



```

PHS=SIN(PHI)
X=.5*(SORT(OI**2+1.27324*ATAUX*PHS/ZK)-OI)/PHS
ELAU=X/COS(PHI)
SIZE=THE DIFFUSER
O2=O.GNM
O1=O1
IF(O2.LT.O1)O2=O1
ELMAX=9.22336*(O2-O1)
ELMIN=2.836075*(O2-O1)
DECIDE WHICH CONDITION GOVERNS THE DIFFUSER.
IF(O1.GT.O2)GO TO 13
  II=2
  GO TO 14
13 CONTINUE
  II=1
  O1IF=O1
  O1IF=O1
  O1IF=O1
  EL=O.5*(ELMAX+ELMIN)
  DEL=0.
  FL=EL+DEL
  KOFX=KOFX+1
  IF(KOFX.GT.10)GO TO 112
  FLD=EL*ENT+EL+3.54491*FL2+ELAU*X
  FL1=5.5*GNM
  ELN=FLD
  IF(FL1.GF.ELD)ELN=FL1
  ELFAC=(FLD-FL1)
  GNM=0.5*(O2+O1)
  XKT=(1.-(O1/O2)**2)**2
  IF(ELFAC.LE.0.)ELFAC=0.
  REL=VO(TI)*ELN/GNU
  RCO=VI(TI)*O1/GNU
  DL=DM/FLN
  CPOC=CFS(REL)*(1.+1.5*O1***(3/2)+.7*.5*DL**3)
  ANGL=0.
  IF(FL.LT.0.001)GO TO 109

```

NACEL252
 NACEL253
 NACEL254
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 NACEL287

-14
 -174
 111

[illegible]

NACEL324
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NACEL357
NACEL358
NACEL359

```

IF(I.EQ.2) PLOSS=OLIP(2)*QO(2)+DDIF
VAOUT=Q(I)*0.53662/(C2*D2)
SQUAR=SIGI(I)+1.-PLOSS/QO(I)

Determine the critical local velocity at the diffuser exit at
which cavitation on the turning vanes occurs.

VCRT=SQRT(SQUAR)*VQ(I)/SQRT(1.+SIGIV)

Estimate the maximum local velocity at the diffuser exit.

VMAX=1.50*VAOUT

If cavitation occurs, reject on design, indicate on evaluation.

IF(VMAX.GT.VCRT.AND.(ISTRT.EQ.1.AND.DELTA.GT.1.E-6)) RETURN
IF(VMAX.GT.VCRT)CAV(I)=1.

At this point the diffuser has been sized to avoid cavitation at
both take/reef and cruise. Internal flow losses are determined

DELH(I,1)=PLOSS/(RHO*G)
REN1=ELN*VQ(I)/GNO

Calculate the drag coefficients.

CO(I)=CFS(REN1)*(1.+1.5*(DM/ELN)**((3/2)+7.)*(DM/ELN)**3)

Calculate wetted surface and drag.

EM=SQRT(1.+4.)*((2.*FEXT)/DM)**2)
AFXM=1.0472*Q*DM*(EM+1./((EM+1.))+PI*DM*(ELN-2.*FEXT)
CPQ(I)=2.*CO(I)*AFXM*CO(I)
CPTIME
AREA(1)=PI*D2*D2*0.5
CGS(1,1)=HS+HF-HCL

```


NACEL360
 NACEL361
 NACEL362
 NACEL363
 NACEL364
 NACEL365
 NACEL366
 NACEL367
 NACEL368

```

CGS(2,1)=XLS+.5*(ELN-3.54421*.02)
IF(THATA(1).GE.90.)GO TO 13
CGS(2,1)=CGS(2,1)+CGS(1,1)/TAN(THATA(1)*.0174533)
10 CGS(3,1)=0.
CGS(4,1)=0.
WGT5(1,1)=.11*DM*AE*EXN*(.5*DHOD-RHOW)+15.07*AREA(1)*(FLENT+ELAUX+
A FL)
RETURN
END
  
```


SUBROUTINE ELBOW
COMMON /H2O/TEMP, DV, RHO, GNV, HA
COMMON /SHIP/ DISP, RANGE, REAM, HS, HF, HCL, XLS, XLPT, XLP
COMMON /CHARS/ WGT(2,15), CGS(4,15), DELH(5,15), CGSX, CGSZ
COMMON /ELBW/XK(4), RD(4), THATA(4), WIDTH, DEPTH, TYPE(3,4)
COMMON /FLOW/O(5), AIN, AJET, AREA(11), VJ(5), VI(5)
COMMON /CONST/PI, C, PHCO
COMMON /INDEX/IEVAL, IEQPT, ISTRT, NUMR, IENGR, ITYPE, ICOMP, NPUMP, NGT
COMMON /TABLE/L(2)

ELBOW PERFORMANCE AND DESIGN

REQUIRED INPUT

WIDTH - WIDTH OF DUCT AT ELBOW INLET
DEPTH - HEIGHT OF DUCT AT ELBOW INLET
XK - RADIUS RATIO, RATIO OF THE RADIUS OF THE CENTERLINE OF
O - REND TO THE INTERNAL RADIUS OF THE DUCT
- FLOW RATE, IN CUBIC FEET PER SECOND
AREA - CROSS SECTIONAL AREA OF DUCT AT THE ELBOW, PRESUMED
THATA - SAME AT THE INLET AND THE OUTLET
GNV - ANGLE OF BEND, FROM HORIZONTAL TO OUTSIDE EDGE
PT - VISCOSITY OF STANDARD (35 PER CENT SALINITY) SALT WATER
ICOMP - INDEX INDICATING WHICH COMPONENT IS BEING LOOKED AT
ISTRT - INDEX NOTING WHICH MODE OF OPERATION FOR THE HYDROFOIL
NUMR - INDEX NOTING HOW MANY MODES TO BE CONSIDERED DURING
THIS PASS

DIMENSION SHAPE(3,4), THETA(11), XLCSS(11), RJA(10)
DATA SHAPE/4H ELL, 4HIPSE, 4H , 4H CIR, 4H CLE , 4H , 4H REC,
A 4H TANG, 4H CLE , 4H SQU, 4H ARE , 4H /
DATA THETA/0., 10., 20., 30., 40., 50., 60., 70., 80., 90., 95./
DATA XLCSS/0., 0.029, 0.059, 0.08, 0.107, 0.133, 0.156, 0.176, 0.198, 0.198,
A0.198/
EPICT(RE)=(.04959*ALOC(PF/(1.964*ALOG(RE)-3.9215)))*(-2)
CORP(RE)=1.00057-.16992*ALOG(RE*1.E-5)+.0145885*ALOG(RE*1.E-5)*2


```

A -.14948E-2*AILOG(REF*1.E-5)**3
  REMAX=4.5+5
  KOUNT=1 STRT
  ICLP=ICOMP-ICOMP/2
  AREA(ICOMP)=AREA(ICOMP-1)
  AREA1=.5*AREA(ICOMP)
  IF(IELB.EQ.4) AREA1=.5*AREA1
  DETERMINE SHAPE
  IJ=0
  IK=1
  IF(WIDTH.EQ.0) IJ=1
  IF(ABS(WIDTH*DEPTH-AREA1).LT..05*AREA1) IK=3
  ITYPE=IJ+IK

```

```

      ITYPE  SHAPE

```

```

      1      ELLIPSE
      2      CIRCLE
      3      RECTANGLE
      4      SQUARE

```

```

  FACTR=(.00225+.041452*XK(IELR)**(-1.86))*XK(IELR)**.84

```

```

  DETERMINE EQUIVALENT RADII

```

```

  R1(IELR)=.5*DEPTH
  IF(ITYPE.EQ.1) R1(IELR)=WIDTH*DEPTH*SORT(2./(WIDTH**2+DEPTH**2))

```

```

  TRANSFER SHAPE TO CALLING PROGRAM

```

```

  DO 1 N=1,3

```

```

    1 TYPE(N,IFLP)=SHAPE(N,ITYPE)

```

```

  FIND BEND RADII

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ELBOW036
ELBOW037
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ELBOW039
ELBOW040
ELBOW041
ELBOW042
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ELBOW067
ELBOW068
ELBOW069
ELBOW070
ELBOW071

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C ELBOW105
C ELBOW106
C ELBOW107

PIN=PO(IELR)*(XK(IELR)-1.)
RINT=PIN+2.*R*(IELR)

IF XK=PI/PO IS LE. 1. DO NOT USE SPLITTERS METHOD....
USE THIN TURNING VANES CALCULATION

IF(XK(IELR).LE.1.) GO TO 100

C DETERMINE NUMBER OF VANES REQUIRED FOR MINIMUM LOSS
C RATIO IS THE OPTIMUM RATIO OF THE INBOARD AND OUTBOARD RADII FOR
C MINIMUM LOSS IN THE BEND

RATIO=4.3
XN=ALOG((XK(IELR)-1.)/(XK(IELR)+1.))/ALOG((RATIO-1.)/(RATIO+1.))
N=XN+.5
IF(N.GT.0) N=1
N1=N-1
IF(N1.LE.0) N1=1

FIND THE RATIO OF THE INSIDE RADIUS TO OUTSIDE RADIUS OF ANY OF
SURDIVIDED ELBOWS

RATED=(PIN/PCUT)**(1./ELCAT(N))

N = NUMBER OF SURDIVIDED ELBOWS
N1 = NUMBER OF SPLITTERS

C COMPUTE HEAD LOSSES FOR EACH SURDIVIDED ELBOW, STARTING FROM INSIDE
C NOTE THE MAXIMUM REYNOLDS NUMBER THE EQUATION IS GOOD FOR, AND
C CORRECT FOR THE ACTUAL REYNOLDS NUMBER IF ABOVE THE MAXIMUM
C N.R. THE REYNOLDS NUMBER IS CALCULATED FROM THE SURDIVIDED ELBOW,
C NOT THE ORIGINAL ELBOW

C SUM=0.
C RIA=PIN

```



```

V=Q(KOUNT)/AREA(ICOMP)
DO 3 I=1,N
  RQA(I)=RIA/RATED
  HGT=FJA(I)-RIA
  AA=PI*HGT*HGT*.25
  IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) AA=WIDTH*HGT
  RAD=HGT*PI*.25
  IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) RAD=.5*(HGT+WIDTH)
  RE=AA*V/(RAD*GNU)
  XCORR=1.
  IF(RC.LT.REMAX) GO TO 7
  XCORR=CORR(RE)/CORR(REMAX)
  RE=REMAX
7  KKT=XCORR*ACTR*THATA(IELR)*RE*(-.17)
  RIA=RQA(I)
3  SUM=SUM+KKT*AA
  HEAD=SUM/ARFAL*.5*V*V/G
  GO TO 5

  THIN,CIRCULAR ARC TURNING VANE CALCULATIONS

100 XCORR=1.
  DIAM=2.*RC(IELR)
  IF(ITYPE.EQ.3.OR.ITYPE.EQ.4) DIAM=2.*WIDTH*DEPTH/(WIDTH**2+DEPTH**2)
  A 2)
  RE=DIAM*V/GNU
  IF(RE.GT.1.E+5) XCORR=CORR(RE)/CORR(1.E+5)
  KKT=TABLF(THETA,XLSS,THATA(IELR),L)
  HEAD=(EPICR(RE)*RC(IELR)*KKT(IELR)*THATA(IELR)*.0174533/PIAM+KKT)
  A *.5*V*V/G*XCORR
5  DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+HEAD
  IF(IELR.EQ.2) DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP)+RC(2)*KX(2)
  IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 4
  KOUNT=KOUNT+1
  IF(XK(IELR).GT.1.) GO TO 6
  V=Q(KOUNT)/AREA(ICOMP)

```


ELROW144
 ELROW145
 ELROW146
 ELROW147
 ELROW148
 ELROW149
 ELROW150
 ELROW151
 ELROW152
 ELROW153
 ELROW154
 ELROW155
 ELROW156
 ELROW157

```

GO TO 100
ELROW STRUCTURE WEIGHT CALCULATIONS
4 VOLV=0.
  IF(XK(IELB),LE.1.) GO TO 0
  DO 0 I=1,N1
    VOLV=VOLV+8.7267E-4*THATA(IELB)*ROA(I)*RIN*WIDTH
    VOL=VOLV+THATA(IELB)*RO(IELB)*XK(IELB)*AREA(ICOMP)/(134.56*RHOD)
    WGT5(1,ICOMP)=VOL*RHOD*G
    WGT5(2,ICOMP)=AREA(ICOMP)*RHOW*G*THATA(IELB)*RO(IELB)*XK(IELB)*
    A .0174533
  RETURN
  END

```



```

1 34.,30.,45.,50.,60.,70.,80.,90./
DATA EXPAN/0.,.005,.015,.03,.05,.09,.17,.3,.4,.5,.7,.8,.91,0.97,
A 1.0,1.03,1.04,1.04,1.037,1.035,1.033,1.03/
EPIC(T(PF))=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))*(-2)

C
C FIND EFFECTIVE LENGTH FOR EITHER GENERALIZED RECTANGLE OR ELLIPSE
WGTS(1,ICOMP)=1.E11
AREA(ICOMP)=2.*AREA(ICOMP-1)
IF(.NOT.IPUMP) GO TO 5
AREA(ICOMP)=AREA(8)
IF(AREA(8).LT.AREA(7).AND.AREA(4).GT.AREA(7)) AREA(ICOMP)=AREA(4)
5 IF(AREA(ICOMP).LT.AREA(ICOMP-1)) AREA(ICOMP)=AREA(ICOMP-1)
ARATC=AREA(ICOMP)/AREA(ICOMP-1)

C
C SIZE STRUT EXTERNAL DIMENSIONS
VL=1.137*VD(1)
SIGMA=(HA*G-PV*G)/(.5*VL*VL)
TC=(SQRT(1.+SIGMA)-1.)/1.15
IF(TC.LT..12) TC=.12
C=SQRT(AREA(ICOMP)/TC)
T=TC*C

C
C T AND C ARE THE THICKNESS AND CHORD AT THE STRUT EXIT

C1=SQRT(AREA(ICOMP-1)/TC)
T1=TC*C1

C1 AND T1 ARE THE CHORD AND THICKNESS AT THE STRUT INLET

CM=.5*(C+C1)

C
C FIND EQUIVALENT DIAMETERS
IF(ITYPE/2.EQ.0) GO TO 1
DEIN=WIDTH*DEPTH/(WIDTH+DEPTH)

```

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STRUT105
STRUT106
STRUT107

```

WIDTH=SQRT(AREA(ICOMP))*0.5
WIDC=2.*WIDTH
PFCUT=WIDC*WIDTH/(WIDE+WIDTH)
R0(2)=0.5*WIDTH
GO TO 2

1 DEFIN=WIDTH*DEPTH*SQRT(2./(WIDTH*WIDTH+DEPTH*DEPTH))
WIDTH=SQRT(AREA(ICOMP)/PI)
WIDC=2.*WIDTH
PFCUT=WIDC*WIDTH*SQRT(2./(WIDE*WIDE+WIDTH*WIDTH))
R0(2)=0.5*PFCUT
DEAV=DEFIN+PFCUT
2 STPH=HS-DC(1)*XK(1)-R0(2)*XK(2)
IF(STR.LF.0.) RETURN
XLONG=STRT/SIN(THETA(1))*0.174533)

FIND EQUIVALENT ANGLE OF DIFFUSER, TWO THETA

STAN=(WIDE-DEPTH)*0.5/XLONG
THETA=2.*ATAN(STAN)*57.29578

FIND EXPANSION COEFFICIENT
ECOFF=TABLE(THET2,EXPAN,THETA,L)

FORM THE EXPANSION LOSS COEFFICIENT
FORML=ECOFF*(1.-1./ARATO)**2

DETERMINE INLET AND OUTLET VELOCITIES

DEPTH=WIDTH
WIDH=WIDC
KOUNT=1STRT
3 VFLIN=O(KOUNT)/AREA(ICOMP-1)
VLCUT=VFLIN/ARATO

```



```

C DETERMINE STRUT DRAG FROM HOERNER
C DETERMINE SPRAY DRAG FROM SHERMAN AND LINCOLN
C
RES=CM*VQ(KCOUNT)/GNU
COS=2.*COS(PES)*(1.+2.*TC+60.*TC**4)
CFM=HS/(HS+HF-PO(2)*XK(2))*(C-C1)+C1
CSTPT(KCOUNT)=COS*PHQW*VQ(KCOUNT)**2*HS/SIN(THATA(1)*.0174533)*.5
A*(CFM+C1)
CDSP=.03*TC
CSPRY(KCOUNT)=CSTRT(KCOUNT)*(CDSP/COS)
C
CALCULATE THE STRAIGHT PIPE FRICTION COEFFICIENT
C
RF=VELIN*DELIN/GNU
PIPEL=FRIC(T(RF)*XLONG/DELIN
C
LOSS COEFFICIENT WHICH IS PROPORTIONAL TO VELOCITY HEAD AT INLET
C
TOTAL=FORML+PIPEL
C
HEAD LOSS DUE TO DIFFUSER
C
HEADL=.5*TOTAL*VELIN*VELIN/G
C
TOTAL HEAD LOSS DUE TO DIFFUSER AND ELEVATION
C
DELH(KCOUNT,ICOMP)=DELH(KCOUNT,ICOMP-1)+HEADL+HF-RO(2)*XK(2)
IF(KCOUNT.EQ.2.OR.KCOUNT.EQ.NUMR) GO TO 4
KCUNT=KCOUNT+1
GO TO 3
C
CENTER OF GRAVITY CALCULATIONS
C
4 HGT=XLONG-HS+PO(1)*XK(1)
CGWS=HGT*(3.*ARATD+2.*SORT(ARATD)+1.)*.25/(APATD+SORT(ARATD)+1.)
CGS(3,ICOMP)=-CGWS

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STRUT108
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 STRUT153

CGS(4,ICOMP)=XLS+CGWS*CONTAN(THATA(1)*.0174533)
 CGS(1,ICOMP)=CGS(3,ICOMP)
 CGS(2,ICOMP)=CGS(4,ICOMP)
 WEIGHT CALCULATIONS
 WGT(1,ICOMP)=.250*(T+T1)*CM*XLONG*PHDW*G
 WGT(2,ICOMP)=HGT/3.*AREA(ICOMP)*(ARAT(1)+SQRT(ARAT(1)))*RHJW*G
 RETURN
 END

C
 C
 C


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JUNCT000
JUNCT001
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JUNCT003
JUNCT004
JUNCT005
JUNCT006
JUNCT007
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JUNCT009
JUNCT010
JUNCT011
JUNCT012
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JUNCT028
JUNCT029
JUNCT030
JUNCT031
JUNCT032
JUNCT033
JUNCT034
JUNCT035

COMMON /H2O/TEMP,PV,RHOW,GNU,HA
COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
COMMON /CHAPS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
COMMON /CONST/PI,G,RHCD
COMMON /ELRW/XK(4),PO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
COMMON /FLOW/Q(5),AJN,AJCT,AREA(11),VJ(5),VI(5)
COMMON /INDEX/JEVAL,IEOPT,ISTRT,NJMB,IENGN,ITYPE,ICOMP,NPUMP,NGT
COMMON /ITABL/L(2)
DIMENSION BETA(19),ALAMD(19)
DATA ALAMD/.975,.97,.967,.963,.96,.957,.953,.95,.948,.945,.94,.93,
A 0.92,0.9,0.85,0.81,0.75,0.59,0.61/
DATA BETA/0.5,10.,15.,20.,25.,30.,35.,40.,45.,50.,55.,60.,65.,70
A,.75,.80,.85,.90./
DATA ALPHA/0./
FRIC(FF)=(.86859*ALOG(RE/(1.964*ALOG(RE)-3.8215)))**(-2)
AREA(ICOMP)=AREA(ICOMP-1)

ALPHA IS ANGLE THAT ONE BRANCH MAKES WITH END PIPE IN JUNCTION
KOUNT=ISTRT

MIXING LOSS COEFFICIENT OF JUNCTION

XLAMD=TABLE(BETA,ALAMD,ALPHA,L)
AMIXL=1.+XLAMD-2.*COS(.024434*ALPHA-.00583*(ALPHA*.0174533)**2)
IF(AMIXL.LT.0.) AMIXL=0.

XPUMP=NGT+1

ASSUMES NO LOSS DUE TO CHANGE OF SHAPE TO CIRCULAR

DIAM=1.414*SQRT(AREA(ICOMP)/PI)
RQ(3)=.66*DIAM
AJCT=XLS-PO(3)*XK(3)-XLP-XLPE
IF(AJCT.LT.0.) AJCT=0.
FLOWG=BEAM/XPUMP-RQ(3)*(1.+XK(3))-RQ(2)*XK(2)+P7(2)

```



```

C      DEPTH=DIAM
C      WIDTH=DEPTH
C      2 ICOMP=5
C      FIND HEAD LOSS FOR ATHWARTSHIPS LENGTH
C
C      V=O(KOUNT)/AREA(ICOMP)
C      RE=V*DIAM/GNU
C      FRCTL=FRIC(T(Re))*FLONG/DIAM
C      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+FRCTL*.5*V*V/G
C      ICOMP=6
C
C      FIND HEAD LOSS IN PUMP ELBOW
C
C      CALL ELBOW
C      RE=Re*.414
C
C      FRICTION LOSS COEFFICIENT IN JUNCTION
C      FRCTJ=.3535*FRIC(T(Re))*AJCT/DIAM+FRCTL*AJCT/FLONG*.5
C
C      TOTAL JUNCTION LOSS COEFFICIENT
C
C      AJCTL=AMIXL+FRCTJ
C
C      HEAD LOSS OF JUNCTION
C
C      ICOMP=7
C      DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+AJCTL*.5*V*V/G
C      IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 1
C      KOUNT=KOUNT+1
C      GO TO 2
C
C      1 AREA(ICOMP)=AREA(ICOMP-1)
C
C      CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF COMPONENTS OF PUMP
C      INLET PIPING.
C
JUNCT036
JUNCT037
JUNCT038
JUNCT039
JUNCT040
JUNCT041
JUNCT042
JUNCT043
JUNCT044
JUNCT045
JUNCT046
JUNCT047
JUNCT048
JUNCT049
JUNCT050
JUNCT051
JUNCT052
JUNCT053
JUNCT054
JUNCT055
JUNCT056
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JUNCT058
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JUNCT063
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JUNCT067
JUNCT068
JUNCT069
JUNCT070
JUNCT071

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JUNCT072
 JUNCT073
 JUNCT074
 JUNCT075
 JUNCT076
 JUNCT077
 JUNCT078
 JUNCT079
 JUNCT080
 JUNCT081
 JUNCT082
 JUNCT083
 JUNCT084
 JUNCT085
 JUNCT086
 JUNCT087
 JUNCT088
 JUNCT089
 JUNCT090
 JUNCT091

CGS(1,6)=HCL
 CGS(2,5)=XLS
 CGS(3,6)=HCL
 CGS(4,6)=XLS
 WCTS(1,5)=13.7*AREA(5)*FLONG
 WCTS(2,5)=AREA(5)*FLONG*PHCW*G
 CGS(1,5)=HCL
 CGS(2,5)=XLS
 CGS(3,5)=HCL
 CGS(4,5)=XLS
 WCTS(1,ICOMP)=13.7*AJCT*AREA(ICOMP)
 WCTS(2,ICOMP)=AJCT*AREA(ICOMP)*PHCW*G
 CGS(1,ICOMP)=HCL
 CGS(2,ICOMP)=XLS-RD(3)*XK(3)*SIN(THATA(3)*.008757)-.5*AJCT
 CGS(3,ICOMP)=HCL
 CGS(4,ICOMP)=CGS(2,ICOMP)
 DEPTH=1.414*DIAM
 WIDTH=DEPTH
 RETURN
 END


```

SURROUTINE PIPE
COMMON /FLW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
COMMON /FLW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
COMMON /CHAPS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
COMMON /CONST/PI,6,RHCD
COMMON /SHIP/DISP,RANGE,REAM,HS,H7,HCL,XLS,XLPE,XLP
COMMON /H2O/TEMP,PV,RH3W,GNU,HA
COMMON /INDX/IFVAL,IEOPT,ISTRT,NUMR,IENGN,ITYPE,ICOMP,NPUMP,NGT
FRICT(PE)=(.83859*ALOG(RE/(1.964*ALOG(PE)-3.9215)))**(-2)
KOUNT=ISTRT
AREA(ICOMP)=AREA(ICOMP-1)
DIAM=1.414*SQRT(AREA(ICOMP)/PI)
DEPTH=DIAM
WIDTH=DEPTH
RO(3)=.5*DIAM
APIPE=XLS-XLP-RO(3)*XK(3)
IF(APIPE.LT.0.) APIPE=0.
XPUMP=NGT
XLONG=REAM/(XPUMP+1.)-RO(3)*XK(3)*SIN(THATA(3)*.008727)-RO(2)*
  A XK(2)+RO(2)
  2 ICOMP=5

FIND HEAD LOSS FOR ATWARTSHIPS LENGTH

V=Q(KOUNT)/AREA(ICOMP)
RE=DIAM*V/GNU
FRCTL=FRICT(PE)*XLONG/DIAM
DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+.5*FRCTL*V*V/G
ICOMP=6

FIND HEAD LOSS IN PUMP ELBOW

CALL ELBOW

LOSS COEFFICIENT

```

PIPE 092
 PIPE 093
 PIPE 094
 PIPE 095
 PIPE 096
 PIPE 097
 PIPE 098
 PIPE 099
 PIPE 100
 PIPE 101
 PIPE 102
 PIPE 103
 PIPE 104
 PIPE 105
 PIPE 106
 PIPE 107
 PIPE 108
 PIPE 109
 PIPE 110
 PIPE 111
 PIPE 112
 PIPE 113
 PIPE 114
 PIPE 115
 PIPE 116
 PIPE 117
 PIPE 118
 PIPE 119
 PIPE 120
 PIPE 121
 PIPE 122
 PIPE 123
 PIPE 124
 PIPE 125
 PIPE 126
 PIPE 127

PIPE 128
 PIPE 129
 PIPE 130
 PIPE 131
 PIPE 132
 PIPE 133
 PIPE 134
 PIPE 135
 PIPE 136
 PIPE 137
 PIPE 138
 PIPE 139
 PIPE 140
 PIPE 141
 PIPE 142
 PIPE 143
 PIPE 144
 PIPE 145
 PIPE 146
 PIPE 147
 PIPE 148
 PIPE 149
 PIPE 150
 PIPE 151
 PIPE 152
 PIPE 153
 PIPE 154
 PIPE 155
 PIPE 156

```

ICOMP=7
XKT=PI*CT(RF)*APIPE/DIAM
DELH(KOUNT,ICOMP)=DELH(KOUNT,ICOMP-1)+.5*XKT*V*V/G
IF(KOUNT.EQ.2.OR.KOUNT.EQ.NUMB) GO TO 1
KOUNT=KOUNT+1
GO TO 2

1 AREA(ICOMP)=AREA(ICOMP-1)

C CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF COMPONENTS OF PUMP
C INLET PIPING
C
WGT(1,5)=13.7*XLONG*AREA(5)
WGT(2,5)=AREA(5)*XLONG*RHO*G
CGS(1,5)=HCL
CGS(2,5)=XLS
CGS(3,5)=HCL
CGS(4,5)=XLS
CGS(1,6)=HCL
CGS(2,6)=XLS
CGS(3,6)=HCL
CGS(4,6)=XLS
WGT(1,ICOMP)=13.7*APIPE*AREA(ICOMP)
WGT(2,ICOMP)=AREA(ICOMP)*APIPE*RHO*G
CGS(1,ICOMP)=HCL
CGS(2,ICOMP)=XLS-RQ(3)*XK(3)*SIN(THATA(3)*.008727)-.5*APIPE
CGS(3,ICOMP)=HCL
CGS(4,ICOMP)=CGS(2,ICOMP)
RETURN
END

```



```

SUBROUTINE DIVRG
  LOGICAL IFUEL, IPUMP
  COMMON /H2O/TEMP,PV,RFJW,GNJ,HA
  COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
  COMMON /CONST/PI,G,RHCD
  COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGS7
  COMMON /FLRW/XK(4),RQ(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
  COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VI(5)
  COMMON /INDEX/IEVAL,IEOPT,ISTRT,NUMR,LENGN,ITYPE,ICOMP,NPUMP,NGT
  COMMON /ITAPL/I(2)
  COMMON IFUEL,IPUMP
  DIMENSION THETA(12),COFF(12)
  DATA THETA/0.,10.,20.,30.,40.,50.,60.,70.,80.,90.,100.,110./
  DATA COFF/0.005,0.04,0.18,0.36,0.57,0.77,0.955,1.14,1.3,1.42,1.5,
  1 1.57/
  FRIC(REF)=(.36859*ALOG(REF/(1.964*ALOG(REF)-3.8215)))**(-2)
  KOUNT=ISTRT
  AREA(ICOMP)=APFA(ICOMP-1)
  DIAM=1.414*SQRT(AREA(ICOMP)/PI)
  RQ(3)=.5*DIAM
  XPUMP=NGT+1
  FLONG=1.5*BEAM/XPUMP-RQ(2)*XK(2)+RQ(2)-RQ(3)*XK(3)*SIN(THATA(3)
  A *.008727)

  CENTER OF GRAVITY AND WEIGHT CALCULATIONS FOR ATHWARTSHIPS LENGTH

  WGTS(1,ICOMP)=13.7*FLONG*AREA(ICOMP)
  WGTS(2,ICOMP)=AREA(ICOMP)*FLONG*RHO*G
  CGS(1,ICOMP)=HCL
  CGS(2,ICOMP)=XLS
  CGS(3,ICOMP)=HCL
  CGS(4,ICOMP)=XLS
  RQ(4)=.3535*DIAM
  3 ICOMP=5

  GET FRICTION LOSS FOR FIRST LENGTH

```


DIVRG036
 DIVRG037
 DIVRG038
 DIVRG039
 DIVRG040
 DIVRG041
 DIVRG042
 DIVRG043
 DIVRG044
 DIVRG045
 DIVRG046
 DIVRG047
 DIVRG048
 DIVRG049
 DIVRG050
 DIVRG051
 DIVRG052
 DIVRG053
 DIVRG054
 DIVRG055
 DIVRG056
 DIVRG057
 DIVRG058
 DIVRG059
 DIVRG060
 DIVRG061
 DIVRG062
 DIVRG063
 DIVRG064
 DIVRG065
 DIVRG066
 DIVRG067
 DIVRG069
 DIVRG069
 DIVRG070
 DIVRG071

```

V=0(KCOUNT)/AREA(ICOMP)
RE=DIAM*V/GNU
FRCTL=FRICT(RE)*FLONG/DIAM
DELH(KCOUNT,ICOMP)=DELH(KCOUNT,ICOMP-1)+FRCTL*.5*V*V/S
WIDTH=DIAM
DEPTH=WIDTH

FIND HEAD LOSS IN PUMP ELBOW

ICOMP=6
CALL ELBOW
ICOMP=7
IF(KCOUNT.NE.1) GO TO 7
THATA(4)=ATAN(PEAM*.5/(XPUMP*(XLS-XLPE-XLP-RQ(3)*XK(3))))
ANGLE=THATA(4)
XLONG=XLS-XLPE-XLP-RQ(3)*XK(3)-RQ(4)*XK(4)
IF(XLONG.GT.0.) GO TO 2
XLONG=0.
THATA(4)=0.
WGTS(1,ICOMP)=0.
ADIV=0.
WGTS(2,ICOMP)=0.
DIVL=0.
ANGLE=0.
DELH(KCOUNT,ICOMP)=DELH(KCOUNT,ICOMP-1)
GO TO 6

2 ADIV=XLONG/COS(ANGLE)
THATA(4)=THATA(4)*57.29578
IF(THATA(4).GT.90.) GO TO 5
DIVL=TANLFT(THETA,COEF,THATA(4),L)
FRCTL=FRICT(RE*.707)*ADIV/DIAM#.414
DIVLC=DIVL+FRCTL
HEADL=DIVLC*V*.5/G
WIDTH=.707*WIDTH
DEPTH=WIDTH
  
```


DIVRG108
DIVRG109

RETURN
END


```

SUBROUTINE N07ZL
LOGICAL IFUEL,IPUMP
COMMON /DRAG/TPDRAG(5),STRID(5),PDO(5),SPRAY(5),REST(5),VJ(5),
1 TPIM(5)
COMMON /FLOW/Q(5),AIN,AJET,AREA(11),VJ(5),VT(5)
COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
COMMON /CONST/PI,G,RHCD
COMMON /SHIP/DISP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
COMMON /H2O/TEMP,PV,RHOW,GNU,HA
COMMON /INDEX/IEVAL,IFOPT,ISTRT,MJMB,IENGN,ITYPE,ICJMP,MPUMP,NGT
COMMON IFUEL,IPUMP
DIMENSION QO(5)
FRICT(RE)=(.3695QALQG(RE)/(1.964*ALQG(RE)-3.8215))**(-2)
KOUNT=ISTRT
XLPS=XLPE
XFAC=1.4*HCL/XLPE
XPUMP=NPUMP
IF(.NOT.IPUMP) AREA(8)=AREA(7)
AREA(ICOMP)=AJET
ANG7=ATAN(TPDRAG(1)/DISP)
XFAC,LT,1. INDICATES N07ZL EXITS THROUGH BOTTOM

IF(XFAC,LT,1.) XLPS=1.4*HCL
XLN7=XLPS/COS(ANG7)
DT=2.*SQRT((AREA(ICOMP)-1)/(PI*XPUMP))
DJ=2.*SQRT(AJET/(PI*XPUMP))
IF(DT,LT,DJ) GO TO 3
1 QO(KOUNT)=Q(KOUNT)/XPUMP
XCORR=XLN7/(DT-DJ)*(1.-(2./(1.+DT/DJ))*4)*VJ(KOUNT)*VJ(KOUNT)/G*N0ZZL029
1.25
RE=Q.*QO(KOUNT)/(PI*(DT+DJ)*GNU)
IF(DJ,LT,1.) XCORR=.0075*VJ(KOUNT)**2/(G*FRICT(RE))
IF(ABS(DT-DJ),LT,.01) XCORR=XLN7/(G*(DT+DJ))*Q(KOUNT)/
A (AREA(ICOMP)-1)+AJET)*.5)**2
DELH(KOUNT,8)=XCORR*FRICT(RE)-XLN7*SIN(ANG7)

```



```

IF (KOUNT.EQ.2.C9.KOUNT.EQ.NUMB) GO TO 2
KOUNT=KOUNT+1
GO TO 1
3 WGT5(1,ICOMP)=1.E20
RETURN
C
C CENTER OF GRAVITY AND WEIGHT CALCULATIONS OF NOZZLE
C
2 CGS(1,ICOMP)=HCL
CGS(2,ICOMP)=XLPE-XLPS*(.25*DT*DT+.5*DT*DJ+.75*DJ*DJ)/(DT*DT+DT*DJ+DT*DJ*DJ)
A=DJ*DJ
CGS(3,ICOMP)=HCL
CGS(4,ICOMP)=CGS(2,ICOMP)
WGT5(2,ICOMP)=XLPS/3.*(AREA(ICOMP-1)+AJET+SQRT(AREA(ICOMP-1)*AJET)
A)=RHQW*G
AREA1=PI*.25*(.152*DT+.056**2)
AJET1=PI*.25*(.152*DJ+.056**2)
WGT5(1,ICOMP)=XLPS/3.*(AREA1+AJET1+SQRT(AREA1*AJET1))*RHQW*G
IF(XFAC.GT.1.) RETURN
CGS(1,ICOMP)=.75*HCL
CGS(3,ICOMP)=CGS(1,ICOMP)
RETURN
END

```



```

SUBROUTINE PUMP                                PUMP 000
PUMP 001
PUMP 002
PUMP 003
PUMP 004
PUMP 005
PUMP 006
PUMP 007
PUMP 008
PUMP 009
PUMP 010
PUMP 011
PUMP 012
PUMP 013
PUMP 014
PUMP 015
PUMP 016
PUMP 017
PUMP 018
PUMP 019
PUMP 020
PUMP 021
PUMP 022
PUMP 023
PUMP 024
PUMP 025
PUMP 026
PUMP 027
PUMP 028
PUMP 029
PUMP 030
PUMP 031
PUMP 032
PUMP 033
PUMP 034
PUMP 035

PUMP JET DESIGN PROGRAM

PUMP JET PROGRAM SOLVES THE PUMP, GEAR, AND FUEL WEIGHTS FOR
BOTH THE MULT-PARALLEL CENTRIFUGAL PUMP AND THE AXIAL PUMP
THE PUMP DESIGN WITH THE LEAST TOTAL WEIGHT IS GIVEN AS THE
OPTIMUM DESIGN FOR THE GIVEN INPUT PARAMETERS

LOGICAL IFUEL, IPUMP
COMMON /CHARS/WGTS(2,15),CGS(4,15),DFLH(5,15),CGSX,CGS7
COMMON /DRAG/TDRAG(5),STPTD(5),PCO(5),SPRAY(5),REST(5),VO(5),
1 TRIM(5)
COMMON /H2O/TEMP,PV,RFOW,GNU,HA
COMMON /SHIP/ DTSP,RANGE,BEAM,HS,HE,HCL,XLS,XLPE,XLP
COMMON /CONST/PI,G,RHDD
COMMON /FLOW/O(5),AIN,AJET,AREA(11),VJ(5),VI(5)
COMMON /INDEX/IEVAL,IEOPT,ISTRT,NPMB,IEGN,I TYPE,ICOMP,NPUMP,NGT
COMMON /WEFT/XWD(5),XWW(5),XWG(5),XWF(5)
COMMON /PSUP/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)
COMMON /PUMP/OO(5),DIS(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5),
A XIM
COMMON /HEAD/HPO(5),HSV(5),THOM(5),PHI(5),WF,WG
COMMON /TOLER/DELTA
COMMON IFUEL, IPUMP
DIMENSION PC(2,3),PCA(2,3),PCC(2,3)
DIMENSION X RPM(11),XCL(11),XD2(11),RPK(11),XPUP(11),YLP(11),
6 XEPAT(11),APUP(5),WRAT(5),WD(10),WW(10),WWG(10)

PUMP CHARACTERISTIC DATA
DATA PC/-3.0,-1.7,4.8,3.42,-0.8,-0.720/
DATA PCA/-1.0,-1.7,1.0,3.42,1.0,-0.72/
DATA PCC/-1.5,-0.75,1.0,1.51,1.0,0.24/

K = CRUISE POINT, J = TAKE OFF POINT
PUMP DESIGN POINT,J, IS AT TAKE OFF BASED ON THOMA'S CRITERION

```



```

C OFF DESIGN POINT,K, IS ANY OTHER POINT ALONG THE DRAG TO SPEED CURVE 036
K=1 PUMP 037
J=2 PUMP 038
DO A I=1,5 PUMP 039
A WRAT(I)=0. PUMP 040
XPUMP=ELCAT(NPUMP) PUMP 041
DO2 I=1,2 PUMP 042
QQ(I)=Q(I)/XPUMP PUMP 043
HPP(I)=(VJ(I)*VJ(I)-VC(I)*VC(I))/(2.*G)+DELH(1,7)+DELH(I,8) PUMP 044
HSV(I)=HA-DELH(I,7)+VC(I)*VJ(I)/(2.*G)-DV PUMP 045
THQW(I)=HSV(I)/HPP(I) PUMP 046
2 CONTINUE PUMP 047
NSTG=1 PUMP 048
IF(HSV(J).LT.0.005) GO TO 10 PUMP 049
PUMP 050
FOR THE VALUE ON THOMAS'S CAVITATION CRITERION LESS THAN THE CUT
OFF POINT, THQW, THE INDUCED PLUS ONE AXIAL STAGE IS REQUIRED
PUMP 051
PUMP 052
THQW=0.055 PUMP 053
IF(THQW(J).LT.THQW1) GO TO 201 PUMP 054
PUMP 055
PUMP 056
PUMP 057
PUMP 058
PUMP 059
SINGLE STAGE INDUCER DESIGN
PUMP CHARACTERISTICS
XNS IS THE SPECIFIC SPEED (CFS) FOR THE FIRST STAGE IN A MULTI-STAGE
DESIGN OR FOR ONE IMPELLER IN A MULTI-DOUBLE SUCTION IMPELLER DESIGN
CM IS THE MAXIMUM SUCTION SPECIFIC SPEED AT TAKE OFF .
PUMP 060
PUMP 061
PUMP 062
PUMP 063
XNS(NSTG)=149.5 PUMP 064
SM(1)=XNS(I)*(1.0/THQW(J))*0.75 PUMP 065
PHI(1)=0.11 PUMP 066
PRAT=0.30 PUMP 067
XXLP=1.70 PUMP 068
CW=347.1*XPUMP PUMP 069
PUMP 070
DESIGN POINT PUMP SPEED PUMP 071

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```

RPM(J,NSTG)=XNS(NSTG)*HPP(J)**0.75/SQRT(QQ(J))
PUMP INLET TIP DIAMETER
DIS(1)=(240.*QQ(J)/(9.4748*PHI(1)*(1.-DRAT**2)*RPM(J,1))**2*(1./3.))
SHI(1)=G*HPP(J)/(PI*RPM(J,1)*DIS(1)/60.)*2
IF(SHI(NSTG).GT.0.41) GO TO 201
ETAP(J,NSTG)=1.0-((3.666/DIS(NSTG)**0.165*(1.-SHI(1)))
QX=QQ(K)/QQ(J)
ETAP(K,1)=ETAP(J,1)*(PC(2,1)*QX**2+PC(2,2)*QX+PC(2,3))
CFF DESIGN PRINT PUMP RPM
CA=PC(1,2)/PC(1,3)*0.5
CB=PC(1,1)/PC(1,3)
HX=HPP(K)/HPP(J)
RX=-CA*QX-SQRT(QX*QX*(CA*CA-CB)+HX/PC(1,3))
RPM(K,NSTG)=RPM(J,NSTG)*RX
PUPAT IS THE CFF DESIGN TO DESIGN FLOW COEFFICIENT RATIO, PHI(K)/PUPAT
PHRAT=OX/OX
DPPY PUMP WEIGHT
203 XWD(NSTG)=CW*DIS(NSTG)**2.3
PLP(NSTG)=DIS(NSTG)*XXLP
ADHP(NSTG)=0.785*DIS(NSTG)**2*(1.-DRAT*DRAT)
D2S(NSTG)=DIS(NSTG)
TNTPAINED WATER WEIGHT
XWW(NSTG)=0.523*ADHP(NSTG)*PLP(NSTG)*RHDW*GX*XPUMP
XNGT=NGT
SHP(2,NSTG)=PHQW*G*Q(2)*HPP(2)/(350.*XNGT*ETAP(2,NSTG)*.98)
GERAT(NSTG)=PERF(4,LENGN)/RPM(J,NSTG)

```



```

IF (GERAT(NSTG).LT.1..AND.DELTA.NF.O.) GO TO 16
CALL GEAR
XWG(NSTG)=WG
DO 3 I=1,2
  ETAPP=ETAP(1,NSTG)*ETAP(7,NSTG)
  SHP(I,NSTG)=RHO*W*G*O(I)*HPP(I)/(550.*XNGT*ETAPP)
  3 IF (SHP(I,NSTG).GT.PERE(I,I*ENG).AND.DELTA.GT.1.E-9) XWW(NSTG)=1.E9PUMP
C
CALL FUEL
XWF(NSTG)=WF
WEAT(NSTG)=(XWD(NSTG)+XWW(NSTG)+XWG(NSTG)+XWF(NSTG))/DISP
GO TO 300
15 XWG(NSTG)=1.E11
GO TO 300
C
INDUCER PLUS ONE AXIAL STAGE DESIGN
201 THOMI=0.058
202 NSTG=2
  HP=HSV(J)/THOMI
C
  THOMS IS THOMA'S CAVITATION CRITERION FOR THE AXIAL STAGE
  BASED ON A MAXIMUM S OF 10,000 AND NS=3619
  THOMS=0.258
C
  INDUCER SPECIFIC SPEED AND FLOW COEFF.
  XNS(NSTG)=140.5
  PHI(2)=0.15
  DRAT=0.3
  XXLDP=1.71
  CW=303.5*XPUMP
C
  DESIGN PUMP SPEED
PUMP 108
PUMP 109
PUMP 110
PUMP 111
PUMP 112
PUMP 113
PUMP 114
PUMP 115
PUMP 116
PUMP 117
PUMP 118
PUMP 119
PUMP 120
PUMP 121
PUMP 122
PUMP 123
PUMP 124
PUMP 125
PUMP 126
PUMP 127
PUMP 128
PUMP 129
PUMP 130
PUMP 131
PUMP 132
PUMP 133
PUMP 134
PUMP 135
PUMP 136
PUMP 137
PUMP 138
PUMP 139
PUMP 140
PUMP 141
PUMP 142
PUMP 143

```



```

RPM(J,NSTG)=XNS(NSTG)*HP**0.75/SQRT(QO(J))
PUMP INLET TIP DIAMETER
DLS(2)=(2*QO(J)/(0.4748*PHI(2)*(1.-ORAT**2)*RPM(J,2))**2)**(1./3.)
ETAP(J,NSTG)=1.0-((3.666/DLS(NSTG))**0.165*(1.-.915))
OX=QO(K)/QO(J)
ETAP(K,NSTG)=ETAP(J,NSTG)*(PCA(2,1)*OX**2+OCA(2,2)*OX+PCA(2,3))
CFF DESIGN POINT RPM
CA=PCA(1,2)/PCA(1,3)*0.5
CR=OCA(1,1)/OCA(1,3)
HX=HDP(K)/HDP(J)
PX=-CA*OX+SQRT(OX*OX*(CA*CA-CR)+HX/PCA(1,3))*(CA/ABS(CA))
RPM(K,NSTG)=RPM(J,NSTG)*RX
PHD AT=OX/PX
SM(NSTG)=XNS(NSTG)*(HP/HSV(J))**0.75
IF((HSV(J)+HP)/(HDP(J)-HP).LT.THDS) GO TO 202
SHI(2)=G*HP/(PI*RPM(J,2)*DLS(2)/60)**2
GO TO 203
INDUCER PLUS TWO AXIAL STAGES DESIGN
MHP=(HDP(J)-HP)/2.0
NSTG=3
XXLP=2.03
CW=439.5*XPUMP
XNS(3)=XNS(2)
SM(3)=SM(2)
DLS(3)=DLS(2)
SHI(3)=SHI(2)
PHI(3)=PHI(2)
RPM(J,3)=RPM(J,2)
RPM(K,3)=RPM(K,2)
ETAP(J,3)=ETAP(J,2)
PUMP 144
PUMP 145
PUMP 146
PUMP 147
PUMP 148
PUMP 149
PUMP 150
PUMP 151
PUMP 152
PUMP 153
PUMP 154
PUMP 155
PUMP 156
PUMP 157
PUMP 158
PUMP 159
PUMP 160
PUMP 161
PUMP 162
PUMP 163
PUMP 164
PUMP 165
PUMP 166
PUMP 167
PUMP 168
PUMP 169
PUMP 170
PUMP 171
PUMP 172
PUMP 173
PUMP 174
PUMP 175
PUMP 176
PUMP 177
PUMP 178
PUMP 179

```

-203-

202 MHP=(HDP(J)-HP)/2.0

NSTG=3

XXLP=2.03

CW=439.5*XPUMP

XNS(3)=XNS(2)

SM(3)=SM(2)

DLS(3)=DLS(2)

SHI(3)=SHI(2)

PHI(3)=PHI(2)

RPM(J,3)=RPM(J,2)

RPM(K,3)=RPM(K,2)

ETAP(J,3)=ETAP(J,2)


```

C      ETAP(K,3)=ETAP(K,2)
C      IF(((HSV(J)+HP)/HHP).LT.THOMS) GO TO 10
C      GO TO 203
C
C      MULTI PARALLEL IMPELLER DESIGN
C
C      300 NSTG=4
C      SM(4)=424.5
C
C      PUMP CHARACTERISTICS
C      THE CENTRIFUGAL IMPELLER DESIGN IS BASED ON A CONSTANT IMPELLER
C      EXIT ANGLE OF 22 DEGREES AND A HYDRAULIC EFFICIENCY OF 0.80
C
C      DRAT=0.50
C      BETA2=2.477
C      XNS(4)=SN(4)*THOM(J)*0.75
C      XNNS=XNS(4)/911.3
C
C      THE IMPELLER EXIT WIDTH RATIO IS ASSUMED TO BE LINEAR WITH NS
C
C      RD=0.001*XNS(4)-0.025
C      IF(XNS(4).LT.50.) RD=0.025
C      CC=SQRT(RD/PI)
C      PHI(4)=0.06
C      14 AA=CC*SQRT(PHI(4))/(0.8*(1.-PHI(4)*BETA2))*0.75
C      IF((XNNS-AA).LE.0.005) GO TO 15
C      PHI(4)=PHI(4)+0.005
C      GO TO 14
C      15 SHI(4)=0.90*(1.-PHI(4)*2.414)
C
C      SPECIFIC SPEED AND PUMP CHARAC. ARE FOR A SINGLE IMPELLER
C
C      PCC(1,3)=XNS(4)/283.85-.17
C      PCC(1,2)=2.5-PCC(1,3)
C
C      IMPL=10

```

PUMP 180
 PUMP 181
 PUMP 182
 PUMP 183
 PUMP 184
 PUMP 185
 PUMP 186
 PUMP 187
 PUMP 188
 PUMP 189
 PUMP 190
 PUMP 191
 PUMP 192
 PUMP 193
 PUMP 194
 PUMP 195
 PUMP 196
 PUMP 197
 PUMP 198
 PUMP 199
 PUMP 200
 PUMP 201
 PUMP 202
 PUMP 203
 PUMP 204
 PUMP 205
 PUMP 206
 PUMP 207
 PUMP 208
 PUMP 209
 PUMP 210
 PUMP 211
 PUMP 212
 PUMP 213
 PUMP 214
 PUMP 215


```

DO5 M=1,IMPL
XIM=EQALS THE NUMBER OF DOUBLE SUCTION IMPELLERS
XIM=EI CAT(M)
QO(J)=Q(J)/(2.0*XIM*XPUMP)
QO(K)=Q(K)/(2.0*XIM*XPUMP)
QX=QO(K)/QO(J)
XPRM(M)=XNS(4)*HPP(J)*0.75/SQRT(QO(J))
XO1(M)=(240.*QO(J)/(0.4748*0.2500*(1.-DET**2)*XRPM(M)))**(1./3.)
XD2(M)=60.0*SQRT(G*HPP(J)/SHI(4))/(PI*XRPM(M))
DEF DESIGN PRINT RDM
CA=PCC(1,2)/PCC(1,3)*C.5
CR=PCC(1,1)/PCC(1,3)
HX=HPP(K)/HPP(J)
EX=-CA*QX+SQRT(QX*QX*(CA*CA-CR)+HX/PCC(1,3))*(CA/ARS(CA))
PRK(M)=XRPM(M)*BX
ETAP(J,1)=1.0-((2.333/XD2(M))*0.165*(1.-.890))
ETAP(K,4)=ETAP(J,4)*(PCC(2,1)*QX*QX+PCC(2,2)*QX+PCC(2,3))
PUMP WEIGHT
XPUP(M)=101.61*Q(J)/(XRPM(M)*XD1(M)*XPUMP)
YLP(M)=SQRT(XPUP(M)/(XIM*0.366))*(1.+XIM)
CW=C.45
WD(M)=(XIM*.725+.275)*CW*XD2(M)*XD2(M)*XNS(4)*XPUMP
WW(M)=0.55*WD(M)
SHP(2,NSTG)=RHOW*G*Q(2)*HPP(2)/(550.*XNGT*ETAP(2,NSTG)*.93)
XPERAT(M)=PERF(4,IFNGN)/XRPM(M)
GERAT(4)=XPERAT(M)
CALL GEAR
WVG(M)=WG
DO7 I=1,2
CTAPP=ETAP(1,NSTG)*ETAP(7,NSTG)
SHP(1,NSTG)=RHOW*G*Q(I)*HPP(I)/(550.*XNGT*ETAPP)

```

PUMP 216
 PUMP 217
 PUMP 218
 PUMP 219
 PUMP 220
 PUMP 221
 PUMP 222
 PUMP 223
 PUMP 224
 PUMP 225
 PUMP 226
 PUMP 227
 PUMP 228
 PUMP 229
 PUMP 230
 PUMP 231
 PUMP 232
 PUMP 233
 PUMP 234
 PUMP 235
 PUMP 236
 PUMP 237
 PUMP 238
 PUMP 239
 PUMP 240
 PUMP 241
 PUMP 242
 PUMP 243
 PUMP 244
 PUMP 245
 PUMP 246
 PUMP 247
 PUMP 248
 PUMP 249
 PUMP 250
 PUMP 251


```

7 IF(SHP(I,NSTG).GT.PERF(I,IFNGN).AND.DELTA.GT.1.E-9) WW(M)=1.E9
  IF(M.EQ.1) GO TO 5
  IF(THCM(J).LT.0.046) GO TO 12
  IF(XERAT(M).LE.1.0) GO TO 6
  IF((WD(M)+WW(M)+WVG(M)).GT.(WD(M-1)+WW(M-1)+WVG(M-1))) GO TO 6
5 CONTINUE
  M=IMPL+1
  GO TO 6
12 WD(M-1)=1.E9
6 XWD(4)=WD(M-1)
  XWW(4)=WW(M-1)
  XWG(4)=WVG(M-1)
  XIM=M-1
  PPM(J,4)=XPPM(M-1)
  DIS(4)=XDI(M-1)
  D2S(4)=XD2(M-1)
  RDM(K,4)=RPM(M-1)
  APUP(4)=XPUP(M-1)
  PLP(4)=YLP(M-1)
  GERAT(4)=XERAT(M-1)
  IF(GRPAT(4).LT.1..AND.DELTA.GT.1.E-9) XWG(4)=1.E9
  CALL FUEL
  XWF(4)=WF
  TOTAL WEIGHT TO DISPLACEMENT RATIO
  WRAT(NSTG)=(XWD(NSTG)+XWW(NSTG)+XWG(NSTG)+XWF(NSTG))/DISP
  N=4
  DO 8 M=1,3
  IF(WRAT(M).NE.0.) GO TO 9
8 CONTINUE
9 CONTINUE
  IF(WRAT(M).GT.WRAT(N)) M=N
  NSTG=M
  XLP=PLP(NSTG)
  IPUMP=.NOT.IPUMP
PUMP 252
PUMP 253
PUMP 254
PUMP 255
PUMP 256
PUMP 257
PUMP 258
PUMP 259
PUMP 260
PUMP 261
PUMP 262
PUMP 263
PUMP 264
PUMP 265
PUMP 266
PUMP 267
PUMP 268
PUMP 269
PUMP 270
PUMP 271
PUMP 272
PUMP 273
PUMP 274
PUMP 275
PUMP 276
PUMP 277
PUMP 278
PUMP 279
PUMP 280
PUMP 281
PUMP 282
PUMP 283
PUMP 284
PUMP 285
PUMP 286
PUMP 287

```


PUMP 288
PUMP 289
PUMP 290
PUMP 291
PUMP 292
PUMP 293
PUMP 294
PUMP 295
PUMP 296
PUMP 297
PUMP 298
PUMP 299
PUMP 300
PUMP 301

WGTS(1,3)=XWD(M)
WGTS(2,8)=XWW(M)
WGTS(1,10)=XWG(M)
WGTS(2,11)=XWF(M)
CGS(1,ICOMP)=HCL
CGS(2,ICOMP)=XLPF+XLP*.5
CGS(3,ICOMP)=HCL
CGS(4,ICOMP)=CGS(2,ICOMP)
AREA(9)=APUP(NSTG)*XPUMP
IF(NSTG.NE.4) XIM=NSTG-1
RETURN
10 WGTS(1,8)=1.E10
RETURN
END


```

SUBROUTINE GEAR
COMMON /INDEX/IEVAL, IEOPT, ISTRT, NUMB, IENG, ITYPE, ICOMP, NPUMP, NGT
COMMON /CONST/PI, G, RHCD
COMMON /PSUB/GEAT(5), SHP(5,5), RPM(5,5), PEPR(5,12), ETAP(8,5)
COMMON /PUMP/OO(5), OIS(5), ODS(5), XNS(5), SMI(5), PLP(5), NSTG, SHI(5),
A XIM
COMMON /HEAD/HBP(5), FSV(5), THOM(5), PHI(5), WF, WG
GEAR PUMP ARRANGEMENT. IF NO. OF PUMPS = S NO. OF GTS, A PLANETARY GEAR
WILL BE USED. IF TWO PUMPS PER GT OR TWO GTS PER PUMP A COMBINING GEAR
REDUCTION GEAR WITH IDLER WILL BE USED.
GEAT=GEAT(NSTG)
IF(GEAT.GT.12.) GO TO 12
IF(NGT-NPUMP) 100,101,102
SUBROUTINE FOR SINGLE REDUCTION GEAR WITH IDLER
100 FAC=1.7
GO TO 3
102 FAC=1.3
IF(GEAT.GT.1.0) GO TO 1
GPAT=1.0
1 C=GEAT*GPAT+1.0
D=SQRT(C*C/64.0+0.00463)
DX=C*0.25-D
X=(C*0.25+D)*(1.0/3.0)+DX/ABS(DX)*ABS(DX)*(1.0/3.0)
FD=(1.0+GEAT**2.0)*(1.0+1.0/X)+X*(1.0+X)
WG=FAC*0.2*FD*SHP(2,NSTG)/PEPR(4,IENG)*ABS(FLGAT(NGT-NPUMP))
ETAP(7,NSTG)=0.98
GO TO 2
SUBROUTINE FOR PLANETARY GEAR WEIGHT
ASSUMED. K FACTOR = 500
ALLOCATION FACTOR = 0.35

```



```

101 IF (GRAT.GT.1.5) GO TO 9
WG=0.0
ETAP(7,NSTG)=1.0
GO TO 2
8 IF (GRAT.GT.2.05) GO TO 9
GRAT=2.05
9 IF (GRAT.GT.4.0) GO TO 10
R=6.0
GO TO 11
10 B=PI/ARSIN( (GRAT-2.0)/GRAT)
11 C=0.4*(GRAT-1.0)*(GRAT-1.0)
E=(C+1.0)/B*0.5
D=SQRT(.25*(.25/27.-E)**2-1./43355.)
DX=-(.25/27.-E)*0.5-D
X=(-(.25/27.-E)*.5+D)*(1./3.)+DX/ABS(DX)*ABS(DX)*(1./3.)
FD=1./B*(1.+1./X)*(1.+X*X*B+C)
WG=0.2*E*O*SHO(2,NSTG)/PERF(4,IFNIGY)*FLJAT(NPUMP)
12 ETAP(7,NSTG)=0.08
GO TO 2
C
C
C
C
DOUBLE REDUCTION DOUBLE BRANCH GEAR DESIGN
GEAR BASED ON A K FACTOR OF 300
12 IF (NGT-NPUMP) 103,104,105
103 FAC=1.7*FLJAT(NPUMP-NGT)
GO TO 13
104 FAC=1.0*FLJAT(NPUMP)
GO TO 13
105 FAC=1.3*FLJAT(NGT-NPUMP)
13 A=GRAT/(GRAT+1.0)
C=(GRAT*GRAT+1.0)*0.2E
D=SQRT((2.*A**3/27.-A*C)**2*.25-A**6/729.)
E=-2.*A**3/27.+A*C
DX=(E-D)*(1./3.)
X=(C+D)*(1./3.)+DX/ABS(DX)*ABS(DX)*(1./3.)
FD=.5*(1.+1./X+4.*X+2.*X*X*(1.+1./GRAT)+2.*GRAT*GRAT/X+GRAT)
GEAR 036
GEAR 037
GEAR 038
GEAR 039
GEAR 040
GEAR 041
GEAR 042
GEAR 043
GEAR 044
GEAR 045
GEAR 046
GEAR 047
GEAR 048
GEAR 049
GEAR 050
GEAR 051
GEAR 052
GEAR 053
GEAR 054
GEAR 055
GEAR 056
GEAR 057
GEAR 058
GEAR 059
GEAR 060
GEAR 061
GEAR 062
GEAR 063
GEAR 064
GEAR 065
GEAR 066
GEAR 067
GEAR 068
GEAR 069
GEAR 070
GEAR 071

```



```

WC=FAC*1.47.*FD*SHD(2,NSTG)/PERF(4,IENGNI)
FTAP(7,NSTG)=0.03
2 CONTINUE
RETURN
END

```

```

GEAR 072
GEAR 073
GEAR 074
GEAR 075
GEAR 076

```



```

SUBROUTINE FUEL
FUEL WEIGHT AT CONSTANT SPEED ASSUMING SFC = CSF*SHIP TO 1/4 AND
COMMON /CHAPS/WTGS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
COMMON /H2O/TMP,PV,RHOW,GNU,HA
COMMON /DRAG/DRAG(5),STRD(5),PDD(5),SPRAY(5),PEST(5),VJ(5),
1 TRIM(5)
COMMON /SHIP/ DISP,RANGT,RCAM,HS,HE,HCL,XLS,XLPE,XLP
COMMON /CONST/PI,G,RHO
COMMON /FLOW/O(5),AIN,AJET,AREA(11),VJ(5),VT(5)
COMMON /INDEX/EVAL,IEOPT,ISTPT,NJMB,IFNGN,ITYPE,ICOMP,NPUMP,NGT
COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)
COMMON /PUMP/OO(5),DIS(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5),
A XIM
COMMON /HEAD/HPP(5),HSV(5),THDM(5),PHI(5),WF,WG
DIMENSION WT(21),DIS(21),VJJ(21)

FUEL CALCULATIONS BASED ON CONSTANT SPEED THROUGHOUT RANGE, DURATI
TRAVEL DIVIDED INTO 20 SEGMENTS AND FUEL WEIGHT CALCULATED ON REV
SHP REQUIREMENTS DUE TO WEIGHT DECREASE

CFS=PERF(3,IFNGN)*PERF(1,IFNGN)**0.25
CA=DRAG(1)/DISP
CO=1.0+ (DELH(1,8) +DELH(1,7))*2.0*G/(VJ(1)*VJ(1))
WT(1)=0.0
DIS(1)=DISP
N=21
XN=20.
TI=RANGT/(VJ(1)*XN)*1.685
IJK=0
XJ=0.75
DO 1 I=2,N
DIS(I)=DIS(I-1)-WT(I-1)
VJJ(I)=VJ(1)/2.0+SQRT(VJ(1)**2/4.0+DIS(I)*CA/(PHI*W*AJET))
H=CO*VJJ(I)*VJJ(I)/(2.*G)-VJ(1)*VJ(1)/(2.*G)+HE
SHPD=(PHI*W*CA*AJET*VJJ(I)*H)/(550.*ETAP(1,NSTG)*ETAP(7,NSTG))
SHNC=SHPD/ELDAT(NGT)
FUEL 000
EFUEL 001
FUEL 002
FUEL 003
FUEL 004
FUEL 005
FUEL 006
FUEL 007
FUEL 008
FUEL 009
FUEL 010
FUEL 011
FUEL 012
FUEL 013
FUEL 014
FUEL 015
FUEL 016
FUEL 017
FUEL 018
FUEL 019
FUEL 020
FUEL 021
FUEL 022
FUEL 023
FUEL 024
FUEL 025
FUEL 026
FUEL 027
FUEL 028
FUEL 029
FUEL 030
FUEL 031
FUEL 032
FUEL 033
FUEL 034
FUEL 035

```


FUEL 036
 FUEL 037
 FUEL 038
 FUEL 039
 FUEL 040
 FUEL 041
 FUEL 042
 FUEL 043
 FUEL 044
 FUEL 045
 FUEL 046

GO TO 4

```

IF (SHNG.GT.0.7*PERF(1,IENGM)).OR.IJK.EQ.1)
  CFS=CFSS*SQRT(SHNG)
  IJK=1
  XJ=0.25
  4 WT(I)=CFS*TI*SHPP**XJ*FLOAT(NGT)**(1.-XJ)
  1 CONTINUE
  DO2 M=2,N
  2 WT(M)=WT(M)+WT(M-1)
  WF=WT(N)
  RETURN
  END
  
```


CFS 000
 CFS 001
 CFS 002
 CFS 003
 CFS 004
 CFS 005
 CFS 006
 CFS 007
 CFS 008
 CFS 009

FUNCTION CFS(P)
 SCHÖENHERR SKIN FRICTION COEFFICIENT
 CFS=0.004
 1 DCFS=(0.242/ALOG10(R*CFS))**2-CFS
 CFS=CFS+DCFS
 IF (DCFS.GT.1.E-6) GO TO 1
 RETURN
 END

TABLE000
TABLE001
TABLE002
TABLE003
TABLE004
TABLE005
TABLE006
TABLE007
TABLE008
TABLE009
TABLE010
TABLE011
TABLE012
TABLE013
TABLE014
TABLE015
TABLE016
TABLE017
TABLE018
TABLE019
TABLE020
TABLE021
TABLE022
TABLE023
TABLE024
TABLE025
TABLE026
TABLE027
TABLE028
TABLE029
TABLE030
TABLE031
TABLE032
TABLE033
TABLE034
TABLE035

```

C      FUNCTION TABLE(XTAB,YTAB,XIN,L)
C      DIMENSION XTAB(2),YTAB(2),X(5),Y(5),A(5),R(5),L(2)
C
C      L(1) - NUMBER OF PAIRS OF DATA POINTS ENTERED
C      L(2) - DEGREE OF FIT, MAXIMUM IS FOUR
C      XTAB - DATA ARRAY OF X VALUES
C      YTAB - DATA ARRAY OF Y VALUES
C      XIN - INDEPENDENT VARIABLE
C      TABLE - DEPENDENT VARIABLE CORRESPONDING TO XIN
C
C      NPTS=L(1)
C      K=L(2)+1
C      IF(K.GT.NPTS) K=NPTS
C
C      BRANCH TO TEN IF X IS INCREASING
C      BRANCH TO 160 IF X IS DECREASING
C      IF XTAB(1).EQ.XTAB(2) ABORT RUN
C
C      IF(XTAB(1)-XTAB(2)) 1C,290,160
C      10 IF(XTAB(1)-XIN) 20,140,200
C      20 DO 120 IX=2,NPTS
C
C      FIND XTAB VALUES BRACKETING XIN
C
C      IF(XTAB(IX).LT.XTAB(IX-1)) GO TO 290
C      IF(XTAB(IX)-XIN) 120,150,40
C      120 CONTINUE
C      GO TO 130
C      40 CONTINUE
C
C      IF XIN LIES BETWEEN EITHER END POINT OF THE XTAB ARRAY AND ITS
C      ADJACENT POINT, THE INTERPOLATION IS LIMITED TO A SECOND DEGREE
C      FIT
C      IF(IX.GT.2) GO TO 60
C      IF(K.GT.3) K=3
C      60 IF(IX.LT.NPTS) GO TO 80

```



```

      IF(K.GT.3) K=3
      80 NDX=IX-K/2
      IF(IX.LT.NPTS) GO TO 100
      NDX=NPTS-K+1
      100 DO 110 IL=1,K
      C
      C      XTAR AND YTAB VALUES FOR THE XTAR VALUES BRACKETING XIN ARE
      C      TRANSFERRED TO THE LAGRANGIAN EQUATION
      C
      X(IL)=XTAB(NDX)
      Y(IL)=YTAB(NDX)
      NDX=NDX+1
      110 CONTINUE
      GO TO 210
      130 CONTINUE
      C
      C      TO GET PAST STATEMENT NUMBER 120, XIN IS LARGER THAN THE LARGEST
      C      VALUE OF X IN XTAB. EXTRAPOLATION IS NECESSARY TO FIND TABLE AT
      C      XIN
      C      TABLE=((YTAB(NPTS)-YTAB(NPTS-1))/(XTAB(NPTS)-XTAB(NPTS-1)))*
      C      A (XIN-XTAB(NPTS))+YTAB(NPTS)
      C      RETURN
      140 IX=1
      150 YTAB=YTAB(IX)
      RETURN
      160 IF(XIN-XTAB(1)) 170,140,200
      170 DO 120 IX=2,NPTS
      C
      C      XTAR IS SEARCHED TO FIND THE VALUE CLOSEST TO XIN
      C
      IF(XTAB(IX).GE.XTAB(IX-1)) GO TO 290
      IF(XIN-XTAB(IX)) 190,150,40
      190 CONTINUE
      GO TO 130
      C
      C      TO GO TO STATEMENT NUMBER 130 INDICATES XIN IS SMALLER THAN THE
      C

```

TABLE036
 TABLE037
 TABLE038
 TABLE039
 TABLE040
 TABLE041
 TABLE042
 TABLE043
 TABLE044
 TABLE045
 TABLE046
 TABLE047
 TABLE048
 TABLE049
 TABLE050
 TABLE051
 TABLE052
 TABLE053
 TABLE054
 TABLE055
 TABLE055
 TABLE057
 TABLE058
 TABLE059
 TABLE060
 TABLE061
 TABLE062
 TABLE063
 TABLE064
 TABLE065
 TABLE066
 TABLE067
 TABLE068
 TABLE069
 TABLE070
 TABLE071


```

C      SMALLEST VALUE OF X IN XTAB AND EXTRAPOLATION IS NECESSARY TO FIND
C      TABLE FOR X IN
200  TABLE=((YTAB(2)-YTAB(1))/(XTAB(2)-XTAB(1)))*(XIN-XTAB(1))+YTAB(1)
      RETURN
210  DO 220 LL=1,K
      A(LL)=1.
220  B(LL)=1.
      P=0.

C      PERFORM LAGRANGIAN INTERPOLATION
C
C      DO 280 N=1,K
C      DO 270 J=1,K
      AA=XIN-X(J)
      IF(J.EQ.N) GO TO 240
      A(N)=A(N)*AA
      RR=X(N)-X(J)
240  IF(RR.EQ.0.) GO TO 270
216  B(N)=B(N)*RR
270  CONTINUE
      C=A(N)/R(N)*Y(N)
      P=P+C
      TABLE=P
      RETURN
C
C      EQUAL CONSECUTIVE OR NON-MONOTONIC VALUES OF X ENCOUNTERED IN XTABLE
C
290  TABLE=1.E30
      RETURN
      END

```

TABLE072
 TABLE073
 TABLE074
 TABLE075
 TABLE076
 TABLE077
 TABLE078
 TABLE079
 TABLE080
 TABLE081
 TABLE082
 TABLE083
 TABLE084
 TABLE085
 TABLE086
 TABLE087
 TABLE088
 TABLE089
 TABLE090
 TABLE091
 TABLE092
 TABLE093
 TABLE094
 TABLE095
 TABLE096
 TABLE097
 TABLE098
 TABLE099
 TABLE100
 TABLE101

SUBROUTINE PTPRN(PSI,SPSI,N,FCT,DEL,DLMIN)

 SUBROUTINE PTPRN
 PURPOSE
 TO FIND THE MINIMUM OF A FUNCTION BY DIRECT SEARCH

 USAGE
 CALL PTPRN(PSI,SPSI,N,FCT,DEL,DLMIN)

 DESCRIPTION OF PARAMETERS
 PSI - A LINEAR ARRAY OF LENGTH N OF COORDINATES OF THE
 ORIGIN OF SEARCH, INPUT
 SPSI - THE MINIMUM VALUE OF THE FUNCTION, OUTPUT
 N - THE NUMBER OF PARAMETERS (COORDINATES) OF THE
 FUNCTION, INPUT
 FCT - THE FUNCTION SUBPROGRAM CONTAINING THE FUNCTION TO
 BE MINIMIZED
 DEL - A LINEAR ARRAY OF LENGTH N CONTAINING THE INITIAL
 STEP SIZE TO BE USED, INPUT
 DLMIN - A LINEAR ARRAY OF LENGTH N CONTAINING THE MINIMUM
 STEP SIZES TO BE USED, INPUT

 SUBROUTINES AND FUNCTION SUBPROGRAMS REQUIRED
 FCT

 REMARKS
 THE CALLING PROGRAM MUST DECLARE THE FUNCTION SUBPROGRAM
 FCT IN AN EXTERNAL STATEMENT

 THIS SUBROUTINE IS A MODIFIED VERSION OF THAT SUGGESTED BY
 HOOKS AND JEEVES AND FOLLOWS THE NOTATION OF THAT PAPER

 REFERENCES
 1. HOOKS AND JEEVES, JACM, 8(2), APR 61, PP 212-229
 2. ALGORITHM 176 AND SUBSEQUENT REMARKS, CACM

PTPRN000
 PTPRN001
 PTPRN002
 PTPRN003
 PTPRN004
 PTPRN005
 PTPRN006
 PTPRN007
 PTPRN008
 PTPRN009
 PTPRN010
 PTPRN011
 PTPRN012
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 PTPRN035


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C .....PTTRN036
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C .....PTTRN043
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C .....PTTRN067
C .....PTTRN068
C .....PTTRN069
C .....PTTRN070
C .....PTTRN071

C .....
C DIMENSION PSI(1),THETA(2),PHI(3),DEL(1),DLIN(1),DIR(3),SAVE(9)
C DATA PH7/.5/
C
C EVALUATE THE FUNCTION AT THE INITIAL POINT
C
C      DO 5 K=1,N
C      5 DIR(K)=0.
C      SPST=FACT(PSI)
C
C      SET THE BASEPOINT
C
C      1 SPST=
C      DO 10 I=1,N
C      10 PHI(I)=PSI(I)
C
C      ICALL=1 INDICATES THE BASEPOINT HAS JUST BEEN UPDATED
C
C      ICALL=1
C
C      MAKE EXPLORATORY MOVES FROM THE BASEPOINT
C
C      GO TO 20
C
C      STORE PREVIOUS POINTS
C
C      2 SPST=
C      DO 11 I=1,M
C      THETA(I)=PSI(I)
C      PSI(I)=PHI(I)
C
C      MAKE PATTERN MOVE (I.E. SIMULTANEOUSLY MOVE THE DISTANCE FROM THE
C      BASEPOINT TO THE PRESENT POINT IN EACH COORDINATE)
C
C      11 PHI(I)=2.*PHI(I)-THETA(I)

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C      SPHI=FACT(PHI)
C      S=SPHI
C      ICALL=2 INDICATES PATTERN MOVE JUST MADE
C      ICALL=2
C      MAKE EXPLORATORY MOVES FROM RESULTING POINT OF PATTERN MOVE
C      GO TO 33
C      DECREMENT STEP SIZE BY A FACTOR OF RHO
C      3 NUMB=0
C      DO 31 I=1,N
C      IF (CFL(I).GT.OLMIN(I)) GO TO 31
C      NUMB=NUMB+1
C      DEL(I)=RHO*DEL(I)
C      -231
C      -19-
C      IF ALL STEP SIZES ARE LESS THAN MINIMUM, RETURN TO CALLING PROGRAM
C      OTHERWISE, START OFF FROM BASEPOINT WITH SMALLER STEP
C      IF (NUMB.EQ.0,N) RETURN
C      GO TO 1
C      MAKE EXPLORATORY MOVES
C      DO 35 K=1,N
C      SAVE(K)=PHI(K)
C      ASSIGN THE DIRECTION OF LAST IMPROVEMENT TO THE CURRENT STEP
C      SIGN=DEL(K)
C      IF (DIR(K).NE.0.) SIGN=DIR(K)/ABS(DIR(K))*DEL(K)
C      PHI(K)=SAVE(K)+SIGN
C      SPHI=FACT(PHI)
PITRN072
PITRN073
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PTTRN108
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PTTRN129
PTTRN130

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IF(SPHI.LT.S) GO TO 96
PHI(K)=SAVE(K)-SIGN
SPHI=ECT(PHI)
IF(SPHI.LT.S) GO TO 96
PHI(K)=SAVE(K)
GO TO 95
96 S=SPHI
95 CONTINUE

IF A EXPLORATORY MOVE IS SUCCESSFUL TRY A PATTERN MOVE IN THAT
DIRECTION. IF ALL EXPLORATORY MOVES ARE UNSUCCESSFUL, DECREASE
STEP SIZE AND RESET BASEPOINT

FOR NORMAL USE OF PTTRN, THE FOLLOWING STATEMENT SHOULD READ
IF(S.GT.SPSI) GO TO (3,1),ICALL
IF(S.GT.SPSI-100.) GO TO (3,1),ICALL

DIR(K) CONTAINS THE SIZE AND DIRECTION OF THE LAST IMPROVEMENT

DO 97 K=1,N
97 DIR(K)=PHI(K)-SAVE(K)
GO TO 2
END

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SUBROUTINE OUTPUT
INTEGER ENGN(3,12)
LOGICAL IFUEL,IPUMP
COMMON /DRAG/TDRAG(5),STPT0(5),PQ0(5),SPRAY(5),REST(5),VQ(5),
1 TRIM(5)
COMMON /CONST/ PI,G,RHCD
COMMON /FLW/Q(5),AIN,AJFT,AREA(11),VJ(5),VI(5)
COMMON /SHIP/ DISP,ORANGE,PCAM,HS,HE,HCL,XLS,XLPE,XLP
COMMON /H2O/TEMP,PV,RH0W,GNU,HA
COMMON /CHARS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
COMMON /STRIC/TC,T,C,T1,C1,CEM
COMMON /PUMP/OQ(5),DIS(5),D2S(5),XNS(5),SM(5),PLP(5),NSTG,SHI(5),
A XIN
COMMON /PSUR/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)
COMMON /HEAD/HPO(5),HSV(5),THOH(5),PHI(5),WF,WG
COMMON /FLRW/XK(6),RO(6),THATA(6),WIDTH,DEPTH,TYPE(3,6)
COMMON /NACIL/DRAT,DM,AI,AIAUX,ELEXT,ELENT,ELAUX,ELDIF,ELN
COMMON /INDEX/EVAL,IEOPT,ISTRT,NIMR,IENGNI,I TYPE,ICOMP,NPUMP,NGT
COMMON IFUEL,IPUMP
DIMENSION VJRT(5),VIPAT(5),HEADL(5,15),CENDS(2,3),FLBWS(2,6),
A PC(5),IAREL(5,14)
DATA CENDS/4H CRU,4HISE,4H T/O,4H,4H EVA,4HL /
DATA FLBWS/4H STF,4HUT,4H HUL,4HL,4H DIV,4HERG
A /
DATA HEADL/75*0./
DATA LARFL/4H NACF,4HLE,3*4H,4HSTRU,4HT FL,4HRTW,2*4H,
A 4HSTRU,4HT DI,4HEFUS,4HER,4H,4HHULL,4H FLB,4HGW,2*4H,
P 4HATHW,4HARTS,4HHIPS,4H LEN,4HGTH,4HPUMP,4H ELB,4HGW,2*4H,
C 4HERFE,4H AND,4H AFT,4H LEN,4HGTH,4HPUMP,4*4H,4HNOZZ,4HLE,
D 3*4H,4HREDU,4HCTIO,4HNGF,4HAR,4H,4HEUFL,4*4H,
F 5*4H,4HJET,4HLIFT,3*4H,4HTOTA,4HLS,3*4H /
DATA ENGN/4HTE35,2*4H,4HTE40,2*4H,4HPRCT,4HEUS,4H1500,
A 4HPORT,4HEUS,4H1000,4HTYNE,4H1A,4H,4HTYNE,4H1C,4H,
B 4HFT12,4HA,4H,4HLM15,4H00,4H,4HLM25,4H00,4H,
C 4HFT48,4H-2C,4H,4HFT4A,4H-12,4H,4HFT4C,4H-2,4H /
IPONT=5

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WRITE(IPRINT,1)
1  FORMAT(5X,4CH '*** WATERJET PROPULSION SYSTEM OUTPUT DATA ***',//)
A 1
DO 7 J=1,STPT,NUMR
  VRAT(J)=VJ(J)/VC(J)
  VIRAT(J)=VI(J)/VC(J)
  HEADL(J,1)=DELH(J,1)
  HEADL(J,2)=DELH(J,2)-DELH(J,1)
  HEADL(J,3)=DELH(J,3)-HEADL(J,2)*XK(2)-DELH(J,2)
  HEADL(J,4)=DELH(J,4)-HEADL(J,3)*XK(2)-DELH(J,3)
  SUM=0.
DO 9 I=5,8
  HEADL(J,I)=DELH(J,I)-DELH(J,I-1)
  IF(I.EQ.8) HEADL(J,8)=DELH(J,8)
  9  SUM=SUM+HEADL(J,I)
  7  HEADL(J,0) =SUM+HEADL(J,1)+HEADL(J,2)+HEADL(J,3)+HEADL(J,4)
  DRAT=AREA(3)/AREA(2)
  WRITE(IPRINT,3) AIN,DRAT,AJET
  3  FORMAT(27H INLET AREA, TOTAL, FEET**2,F8.2,/,
    A 27H STRUT DIFFUSER AREA RATIO, F8.2,/,
    B 25H JET AREA, TOTAL, FEET**2,2X,F8.2,/)
  IK=NPUMP+2-NPUMP/2
  XNGT=NGT
DO 30 K=1,STPT,NUMR
  PC(K)=TDAG(K)*VG(K)/(550.*SHP(K,NGTG)*XNGT)
  WRITE(IPRINT,12)
  12  FORMAT(24X,3HJET,15X,5HINLET)
  WRITE(IPRINT,11)
  IF A EXPLORATORY MOVE IS SUCCESSFUL TRY A PATTERN MOVE IN THAT
  DIRECTION. IF ALL EXPLORATORY MOVES ARE UNSUCCESSFUL, DECREASE
  STEP SIZE AND RESET THE BASEPOINT.
  11  FORMAT(10H FLOW RATE,5X,3HJET,4X,8HVELOCITY,2X,6H INLET,2X,
    A 8HVELOCITY,3X,7HSHR PER,2X,10HIMPULSIVE)
  WRITE(IPRINT,13)
  13  FORMAT(4X,3HCFES,5X,8HVELOCITY,3X,5HSHRATIO,3X,8HVELOCITY,3X,5HSHRATIO,
    A 4X,7HJET,2X,11HCOEFFICIENT)

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OUTPT036
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WRITE(IPRNT,10) (O(I),VJ(I),VJCAT(I),VI(I),VIRAT(I),SHR(I,NSTG),
A PC(I),(COND(S(J,I),J=1,2),I=1,ISTRT,NUMB)
10 FORMAT(F6.2,1X,F6.2,1X,F7.2,3X,F6.2,2X,F6.2,4X,F6.0,2X,F6.4,3X,
A 2A4)
WRITE(IPRNT,16)
16 FORMAT(/,5X,6HRADIUS,5X,4HDUCT,5X,5HANGLE)
WRITE(IPRNT,17)
17 FORMAT(5X,5HRATIO,5X,6HRADIUS,3X,7HDEGREES,5X,8HLOCATION,4X,5HSHAPE
A5,/)
WRITE(IPRNT,18) (XK(I),RO(I),THATA(I),(ELRWS(L,I),L=1,2),(TYPE(L,
A ),L=1,3),I=1,IK)
18 FORMAT(4X,F4.2,6X,F4.2,5X,F5.2,5X,2A4,4X,3A4)
WRITE(IPRNT,20)
20 FORMAT(/,/)
D1 2 K=1,3
2 LABEL(K,12)=FNGN(K,IENGH)
WRITE(IPRNT,27)
27 FORMAT(4X,6HCRUISE,3X,3HT/0,6X,10HEVALUATION)
WRITE(IPRNT,28)
28 FORMAT(28X,6HSTRUCTURE,3X,5HWATER,5X,4HDUCT,4X,4HDUCT,3X,4HDUCT)
WRITE(IPRNT,29)
29 FORMAT(25X,7HWEIGHTS,3X,7HWEIGHTS,3X,6HLOSSES,2X,6HLOSSES,6X,
A 6HLOSSES)
WRITE(IPRNT,40)
40 FORMAT(25X,8H(POUNDS),1X,8H(POUNDS),3X,6H(FEET),2X,6H(FEET),6X,
A 6H(FEET),/)
D1 5 K=1,14
LL=K
IF(K.GT.7) GO TO 9
4 KLL=ISTRT+NUMB-2
GO TO (31,32,33,34,35,36),KLL
31 WRITE(IPRNT,25) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),
A J=1,ISTRT,NUMB)
25 FORMAT(1X,F4.4,5X,2F10.1,2F8.2)
GO TO 5
32 WRITE(IPRNT,37) (LABEL(M,K),M=1,5),(WGTS(I,K),I=1,2),(HEADL(J,LL),OUTPT107

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      A J=I STRT, NUMP)
37 FORMAT(1X,5A4,5X,2F10.1,2F8.2,8X,F8.2)
      GO TO 5
33 WRITE(IPRNT,38) (LABEL(M,K), M=1,5), (WGTS(I,K), I=1,2), (HEADL(J,LL),
      A J=I STRT, NUMP)
38 FORMAT(1X,5A4,5X,2F10.1,2F8.2,4X,2F8.2)
      GO TO 5
34 IF(I STRT.EQ.1) GO TO 40
      WRITE(IPRNT,39) (LABEL(M,K), M=1,5), (WGTS(I,K), I=1,2), (HEADL(J,LL),
      A J=I STRT, NUMP)
39 FORMAT(1X,5A4,5X,2F10.1,24X,F8.2)
      GO TO 5
40 WRITE(IPRNT,41) (LABEL(M,K), M=1,5), (WGTS(I,K), I=1,2), (HEADL(J,LL),
      A J=I STRT, NUMP)
41 FORMAT(1X,5A4,5X,2F10.1,5F8.2)
      GO TO 5
35 WRITE(IPRNT,42) (LABEL(M,K), M=1,5), (WGTS(I,K), I=1,2), (HEADL(J,LL),
      A J=I STRT, NUMP)
42 FORMAT(1X,5A4,5X,2F10.1,20X,2F8.2)
      GO TO 5
36 WRITE(IPRNT,43) (LABEL(M,K), M=1,5), (WGTS(I,K), I=1,2), (HEADL(J,LL),
      A J=I STRT, NUMP)
43 FORMAT(1X,5A4,5X,2F10.1,14X,3F8.2)
      GO TO 5
3 IF(K.EQ.0) IL=8
      IF(K.EQ.14) LI=3
      IF(K.EQ.14) WRITE(IPRNT,26)
24 FORMAT( 24X,60(14-))
      IF(LL.NE.K) GO TO 4
      WRITE(IPRNT,25) (LABEL(M,K), M=1,5), (WGTS(I,K), I=1,2)
5 CONTINUE
      WRITE(IPRNT,6)
      NIMP=XIM
      WRITE(IPRNT,21)
21 FORMAT(15X,CHDUMP DATA,/)
      IF(NISTG.EQ.4) GO TO 48

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OUTPUT108
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OUTPUT143

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WRITE(IPRNT,45) NIMP
45 FORMAT(39H AXIAL PUMP WITH INDUCER IMPELLER AND ,12,17H ADDITIONAL
A STAGE,/)
GO TO 49
48 WRITE(IPRNT,50) NIMP
50 FORMAT(23H CENTRIFUGAL PUMP WITH ,12,34H DOUBLE SUCTION IMPELLERS
AFTER PUMP,/)
49 WRITE(IPRNT,51)
51 FORMAT(5X,4HHEAD,3X,4HPSH,3X,4HTHMA,5X,3HDPH,3X,10HEFFICIENCY)
WRITE(IPRNT,52) (HPP(I),HSV(I),THM(I),RPM(I,NSTG),ETAP(I,NSTG),
A (COPDS(J,I),J=1,2),I=1,ISTP,NUMR)
52 FORMAT(4X,F6.1,2X,F6.1,3X,F5.3,3X,F6.1,4X,F5.3,5X,2A4)
WRITE(IPRNT,53) XNS(NSTG),SM(NSTG),PHI(NSTG),SHI(NSTG),DIS(NSTG),
A D2S(NSTG),XLP
53 FORMAT(/,19H SPECIFIC SPEED,CFS,15(1H.),F7.1,/,
A 27H SUCTION SPECIFIC SPEED,CFS,3(1H.),F7.1,/,
B 17H FLOW COEFFICIENT,18(1H.),F7.3,/,17H HEAD COEFFICIENT,18(1H.),
C F7.3,/,24H INLET TIP DIAMETER,FEET,11(1H.),F7.2,/,
D 23H EXIT TIP DIAMETER,FEET,12(1H.),F7.2,/,
E 17H PUMP LENGTH,FEET,18(1H.),F7.2)
WRITE(IPRNT,57) GERAT(NSTG)
57 FORMAT(11H GEAR RATIO,24(1H.),F7.2,///)
WRITE(IPRNT,24)
24 FORMAT(15X,12HNACELLE DATA,/)
54 WRITE(IPRNT,54) PRAT,DM,AI,AIAUX,FLEXT,ELENT
54 FORMAT(21H DIAMETER RATIO,DI/DM,19(1H.),F6.3,/,
A 25H MAXIMUM DIAMETER,DM,FEET,15(1H.),F6.2,/,
B 29H INLET AREA PER NACELLE,ET*2,11(1H.),F6.2,/,
C 35H AUXILIARY INLET AREA PER NACELLE,ET*2,F7.2,/,
D 21H BODY LENGTH,FEET,19(1H.),F6.2,/,
E 14H LIP LENGTH,FEET,24(1H.),F6.2)
WRITE(IPRNT,55) ELDIF,ELN
55 FORMAT(21H DIFFUSER LENGTH,FEET,19(1H.),F6.2,/,
A 20H NACELLE LENGTH,FEET,20(1H.),F6.2,/)
TCM=TC*CFM
WRITE(IPRNT,47) TC,T,C,T1,C1,TFM,CFM

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47 FORMAT (10X, 10HSTRUCT CONFIGURATION, //,
   A 3X, 34T/C, 5X, 5HTHICKNESS, 5X, 5HCHORD, /,
   B 1X, F5.3, 7X, F4.1, 5X, F6.1, 5X, 4H200T, /,
   C 13X, F4.1, 5X, F4.1, 5X, 34T IP, /,
   D 13X, F4.1, 5X, F4.1, 5X, 5HCHWATERLINE, //)
   WRITE (IPRNT, 56) (TOPAC(I), 200(I), STRID(I), SPRAY(I),
   A (C-INDS(J,I), J=1,2), I=1,STRT, NUMR)
56 FORMAT (10X, 14HOPAG ESTIMATES, /, 5X, 5HTOTAL, 5X, 7HNACELL, 5X, 5HSTPUT,
   A 5X, 5HSPRAY, /, (1X, F6.1, 5X, F7.1, 4X, F6.1, 5X, F6.1, 5X, 2A4))
   WTRATE=(WGTS(1,14)+WGTS(2,14))/DISP
   WPRATE=(IPRNT, 23) WTRATE
23 FORMAT (/, 30H TOTAL SYSTEM WEIGHT RATIO IS , F6.4)
   WRATE=(WGTS(1,14)+WGTS(2,14)-WGTS(2,11))/DISP
   WRITE (IPRNT, 26) WRATE
46 FORMAT (/, 37H SYSTEM WEIGHT RATIO WITHOUT FUEL IS , F6.4)
   WRITE (IPRNT, 4)
6 FORMAT (1H1)
   RETURN
   END

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```

BLOCK DATA
COMMON /PARMS/ VJVO,VIVO,DIDM
COMMON /STRIC/TC,T,C,TI,CI,CFM
COMMON /PUMP/OO(5),OIS(5),O2S(5),XNS(5),SM(5),FLP(5),NSTG,SHI(5),
A XIM
COMMON /H2O/TEMP,PV,PHW,GNU,HA
COMMON /SHIP/DISP,RANGE,RFAM,HS,HE,HCL,XLS,XLPF,XLP
COMMON /CONST/PI,G,PHCO
COMMON /CHAPS/WGTS(2,15),CGS(4,15),DELH(5,15),CGSX,CGSZ
COMMON /FLPW/XK(4),RO(4),THATA(4),WIDTH,DEPTH,TYPE(3,4)
COMMON /TOLCR/DELTA
COMMON /FLCW/O(5),AIN,AJET,AREA(11),VJ(5),VI(5)
COMMON /PSUB/GERAT(5),SHP(5,5),RPM(5,5),PERF(5,12),ETAP(8,5)
COMMON /NACCL/PRAT,DM,AI,AIAUX,ELEXT,ELENT,FLAUX,ELDIF,FLN
COMMON /INDEX/IFVAL,IFOPT,ISTRT,NJMR,IENGN,I TYPE,ICOMP,NPUMP,NGT
COMMON /ITABL/I(2)
DATA TEMP/59./
DATA HS,HE,HCL,XLS,XLPF,XLP/5.,10.,2.,20.,2.,0./
DATA PI,G,PHCO/3.14159,32.174,14.92/
ENGINE PERFORMANCE DATA
DATA PERF/2220.,2840.,59,14500.,1050.,2850.,3060.,55,14500.,
11050.,2800.,3510.,43,1500.,3200.,2800.,3510.,43,1000.,3300.,
23320.,4250.,48,3110.,2300.,4160.,5300.,47,3110.,2300.,
32220.,2820.,79,9000.,1010.,12500.,14000.,575,5500.,7500.,
422200.,22500.,41,3400.,10500.,19150.,24200.,52,3600.,14200.,
521750.,26050.,52,3600.,14200.,27500.,34400.,48,3600.,14200./
DATA WGTS,CGS,DELH/165*0./
DATA PRAT,DM,AI,AIAUX,ELEXT,ELENT,FLAUX,ELDIF,FLN/6*1./
DATA RO/4*1./,XIM/1./
DATA TC,T,C,TI,CI,CFM/6*1./
DATA THATA,XK/3*90.,30.,3*1.5,2./
DATA SHP/25*1000./,DELTA/.05/
DATA VJVC,VJVO,DIDM/1.8,7.,7./
DATA O,VJ,VI,AREA/15*0.,11*1./
DATA IFOPT,IENGN,IFVAL/0,8,0/
DATA L/11,1/

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RLKDT036
RLKDT037
RLKDT038

DATA TYPE/12-4-4
DATA NSTG/1/
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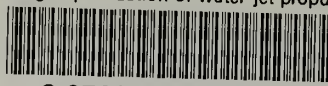
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